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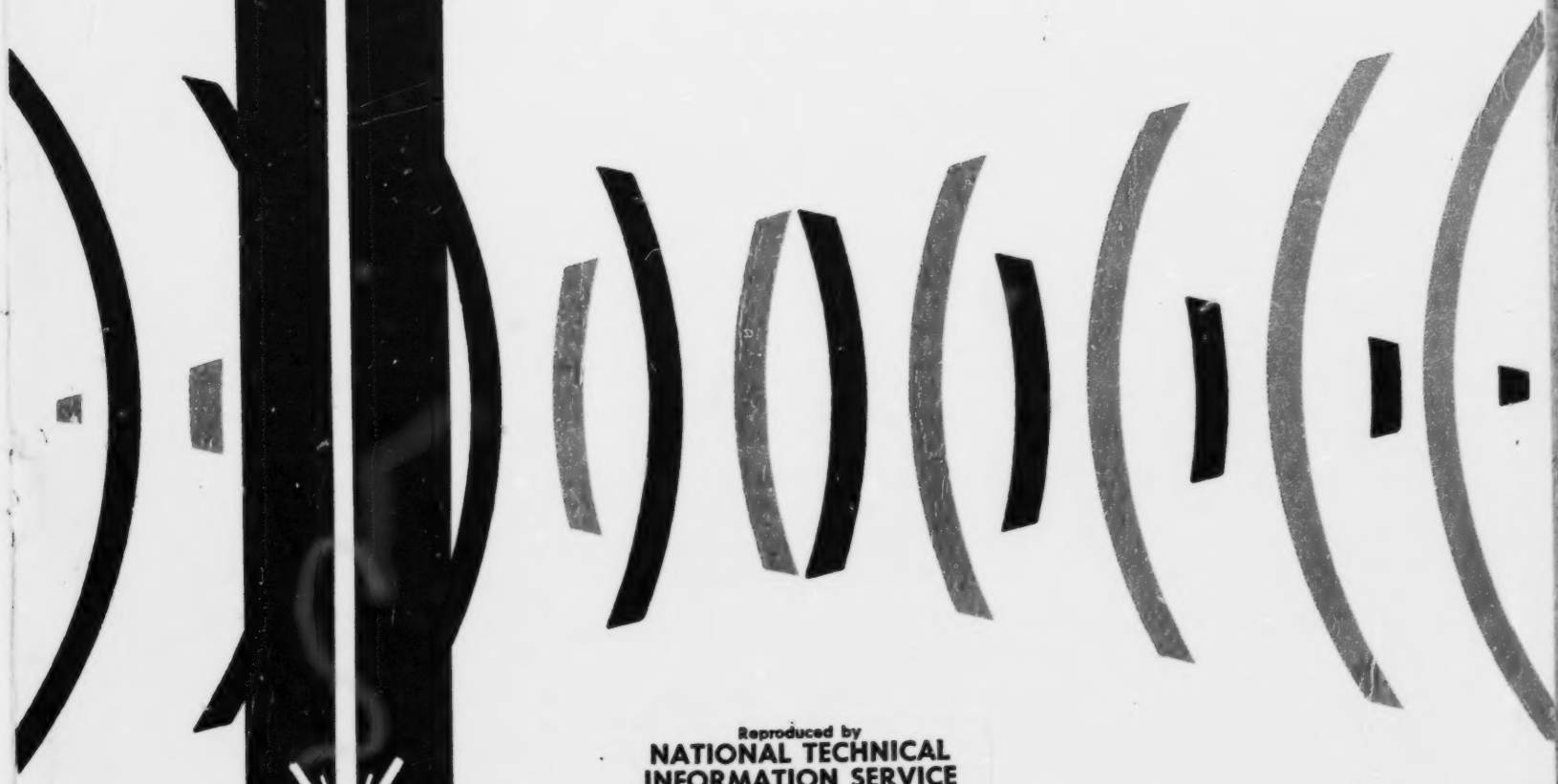
# MEASUREMENT of ELECTROMAGNETIC RADIATION LEVELS FROM SELECTED TRANSMITTERS OPERATING BETWEEN 54 and 220 MHz in the LAS VEGAS, NEVADA, AREA



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# MEASUREMENT of ELECTROMAGNETIC RADIATION LEVELS FROM SELECTED TRANSMITTERS OPERATING BETWEEN 54 and 220 MHz in the LAS VEGAS, NEVADA, AREA

Kenneth R. Envall
Richard W. Peterson
Harold F. Stewart

Division of Electronic Products

Details of illustrations in this document may be better studied on microfiche

September 1971

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
FOOD AND DRUG ADMINISTRATION
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| BIBLIOGRAPHIC DATA SHEET | 1. Report No. BRH/DEP 72-4 | 2. | 3. Recipient's Accession No. |
|---|---|---|---|
| 4. Title and Subtitle<br>Measurement of Electromagnetic Radiation Levels From Selected Transmitters Operating Between 54 and 220 MHz in the Las Vegas, Nevada, Area. | | | 5. Report Date<br>September 1971<br>6. |
| 7. Author(s)<br>Kenneth R. Envall, Richard W. Peterson, Harold F. Stewart | | | 8. Performing Organization Rept. No. BRH/DEP 72-4 |
| 9. Performing Organization Name and Address<br>U. S. Department of Health, Education, and Welfare<br>Bureau of Radiological Health<br>Rockville, Md. 20852 | | | 10. Project/Task/Work Unit No.<br>11. Contract/Grant No. |
| 12. Sponsoring Organization Name and Address<br>Same as above | | | 13. Type of Report & Period Covered<br>14. |
| 15. Supplementary Notes | | | |

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

| 18. Availability Statement | 19. Security Class (This Report) | 21. No. of Pages |
|---|---|---|
| SOD Order No. HE 20.4110:72-4<br>Avail. Supt. of Docs. Price 75 Cents<br>Release unlimited | UNCLASSIFIED | 87 |
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# FOREWORD

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Within the Bureau, the Division of Electronic Products (1) develops and administers performance standards for radiation emissions from electronic products, (2) studies and evaluates emissions of and conditions of exposure to electronic product radiation and intense magnetic fields, (3) conducts or supports research, training development, and inspections to control and minimize such hazards, and (4) tests and evaluates the effectiveness of procedures and techniques for minimizing such exposures.

The Bureau publishes its findings in appropriate scientific journals and technical report and technical note series for the Bureau's divisions, offices, and laboratories.

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I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

John C. Villforth
Director
Bureau of Radiological Health

## PREFACE

One of the requirements of the Radiation Control for Health and Safety Act of 1968, which was enacted to protect the public from exposure to radiation from electronic products, is that programs be carried out to study and evaluate emissions of and conditions of exposure to electronic product radiation. In implementation of this requirement, a study has been made of the relationship between the experimentally observed and theoretically calculated power levels from selected transmitters operating between 54 and 220 MHz in the Las Vegas, Nevada, area.

The study was designed and carried out by the Laser Section at the Bureau of Radiological Health's Southwestern Radiological Health Laboratory. As a result of the Bureau's recent reorganization, the personnel responsible for the project have been reassigned to the Division of Electronic Products. This report describes their methodology and instrumentation and presents an analysis and evaluation of the data obtained.

Robert L. Elder, Sc.D.
Director
Division of Electronic Products

ACKNOWLEDGEMENTS

The authors would like to express their appreciation for the theoretical and practical support efforts given this project by Mr. Art Jarvis of the Western Environmental Research Laboratory (formerly the Southwestern Radiological Health Laboratory) Training Staff and for the review and assistance provided by Dr. Albrecht P. Barsis, Chief, Systems Engineering and Analysis, of the Institute for Telecommunication Sciences, Boulder, Colorado.

CONTENTS


| | Page |
|---|---|
| FOREWORD | iii |
| PREFACE | v |
| ACKNOWLEDGEMENTS | vi |
| FIGURES | viii |
| ABSTRACT | ix |
| 1. INTRODUCTION | 1 |
| 2. INSTRUMENTATION AND METHODOLOGY | 3 |
| 3. FIELD MEASUREMENTS WITH A DIPOLE ANTENNA | 9 |
| 3.1 DIPOLE CONSTRUCTION AND CALIBRATION | 9 |
| 3.2 CALIBRATION OF SPECTRUM ANALYZER | 13 |
| 3.3 FIELD MEASUREMENTS AT NINE SELECTED GRID LOCATIONS | 16 |
| 3.3.1 Procedure | 16 |
| 3.3.2 Results | 16 |
| 4. FIELD MEASUREMENTS WITH A BICONICAL ANTENNA | 17 |
| 4.1 CONSTRUCTION OF SWRHL BICONICAL ANTENNA AND BALUN | 17 |
| 4.2 CALIBRATION OF SWRHL BICONICAL ANTENNA | 17 |
| 4.3 ANGULAR DEPENDENCE OF BICONICAL ANTENNA | 19 |
| 4.4 TWENTY-FOUR HOUR SURVEILLANCE | 19 |
| 4.5 POWER VARIATION WITH RECEIVING ANTENNA HEIGHT | 22 |
| 4.6 POWER VARIATION WITH DISTANCE FROM A GRID POINT | 22 |
| 4.7 FIELD MEASUREMENTS AT 62 GRID LOCATIONS | 25 |
| 4.7.1 Procedure | 25 |
| 4.7.2 Results and Calculations of Theoretical Power | 26 |
| 5. OBSERVED POWER DENSITIES | 30 |
| 6. DISCUSSION | 31 |
| 7. CONCLUSIONS | 37 |
| REFERENCES | 38 |

Page

APPENDIX A - LIST OF TRANSMITTERS IN THE LAS VEGAS, NEVADA, AREA . . . 41

APPENDIX B - DESCRIPTION OF SAMPLING SITES . . . . . 45

APPENDIX C - COMPUTER PROGRAM FOR DETERMINING DISTANCE, ANGLES, AND CALCULATED POWER LEVELS . . . . . 53

APPENDIX D - DIPOLE ANTENNA DATA . . . . . 57

APPENDIX E - BICONICAL ANTENNA DATA . . . . . 61

APPENDIX F - OBSERVED POWER DENSITY USING THE SWRHL DIPOLE ANTENNA . . 69

APPENDIX G - OBSERVED POWER DENSITY USING THE BICONICAL ANTENNA. . . . 73

FIGURES

Figure 1. Field measurements trailer . . . . . 4

Figure 2. Field measurements instrumentation . . . . . 4

Figure 3. Floor plan of the field measurements trailer . . . . . 5

Figure 4. Sampling locations and transmitters . . . . . 7

Figure 5. SWRHL dipole antenna . . . . . 10

Figure 6. Calibration factor for SWRHL dipole antenna . . . . . 12

Figure 7. Comparison of spectrum analyzer and power meter measurements . . . . . 14

Figure 8. Signal amplitude versus power at 105 MHz . . . . . 15

Figure 9. Calibration setup for test antenna . . . . . 18

Figure 10. Calibration factor for SWRHL biconical antenna . . . . . 20

Figure 11. Relative power versus antenna angle . . . . . 21

Figure 12. Relative power versus antenna height . . . . . 23

Figure 13. Power variation with distance from a grid point . . . . . 24

Figure 14. Block diagram of field measurement instrumentation . . . . 27

Figure 15. Direct and reflected propagation paths for electromagnetic signals on a plane earth . . . . . 32

Figure 16. Observed versus theoretical power for SWRHL dipole antenna measurements . . . . . 34

Figure 17. Observed versus theoretical power for KSHO-TV (video), measured with biconical antenna . . . . . 35

Figure 18. Ratio of observed to theoretical power versus distance for KSHO-TV (video) . . . . . 36

## ABSTRACT

Electromagnetic power levels were measured and compared with theoretical power levels from selected transmitters operating in the frequency range of 54 to 220 MHz in the Las Vegas, Nevada, area. The field measurements were made at 62 grid locations by means of calibrated dipole and biconical antennas. Power variations with respect to antenna height, time of day, distance from a grid point, angular dependence, and terrain were investigated. The data were evaluated in terms of observed and theoretical power levels and converted to power densities for hazards analysis applications. The results indicate that estimates of theoretical power levels should serve as a satisfactory measure of population exposure to electromagnetic energy in the frequency range considered.

# MEASUREMENT OF ELECTROMAGNETIC RADIATION LEVELS FROM SELECTED TRANSMITTERS OPERATING BETWEEN 54 and 220 MHz in the LAS VEGAS, NEVADA, AREA

## 1. INTRODUCTION

The passage of the Radiation Control for Health and Safety Act of 1968 (1) was a formal expression of concern by many scientists, legislators and public health officials about the increasing public use of electronic products emitting either ionizing or nonionizing radiation and the concomitant hazards. The Act provides for the encouragement and support of research to minimize radiation exposure, to determine the biological effects of such exposure, and to develop instrumentation and methods for measuring radiation emissions.

In accordance with the Act, concern has been directed toward the increasing applications and use of the electromagnetic spectrum. Examples of the expanding use of radiation in the VHF, UHF, and microwave portion of the electromagnetic spectrum are television transmitters, air traffic control facilities, two-way service communications, radar installations, satellite communications, weather radar units, and microwave ovens. This increased use of the electromagnetic spectrum is resulting in an increase in the electronic product radiation levels to which people are exposed. Therefore, it is essential to develop methods to reliably assess electromagnetic levels for evaluation of potential health hazards.

A national inventory of microwave towers, broadcasting transmitters, and fixed radar sets, as of July 1969, was conducted jointly by the Bureau of Radiological Health and the Electromagnetic Compatibility Analysis Center (ECAC) (2). This study indicated that in the United States there are 16,272 broadcasting stations (including commercial and educational TV, and FM and AM radio), and 71,524 microwave towers that make use of 191,517 different frequencies. It was also noted that the number of transmitter towers increased by 15 percent each year to satisfy the demand for better communication.

The 1969 Annual Report to Congress on the Administration of the Radiation Control for Health and Safety Act of 1968 (3), presented the following estimates of selective transmitters in use in the United States in January 1970:

| | |
|---|---|
| Commercial Television | 700 |
| Educational Television | 200 |
| Commercial FM | 2,200 |
| Commercial AM | 4,300 |
| Aviation Services | 200,000 |
| Industrial Services | 1,700,000 |
| Public Safety Services | 700,000 |
| Transportation Services | 500,000 |
| Television Translators and Boosters | 2,200 |

Many of these transmitters operate in the frequency range of 54 to 220 MHz. The Federal Communication Commission (FCC) lists over 350 transmitters allocated for non-Federal Government use in this frequency range in the Las Vegas area (35-30-00 N. to 36-30-00 N. latitude and 114-30-00 W. to 115-30-00 W. longitude) (4). The list does not include Federal Government stations which are not authorized by the FCC but receive authorization from the Interdepartment Radio Advisory Committee (IRAC) or amateur radio transmitters operating in this frequency range.

As a direct result of the Radiation Control Act, the Laser Section (formerly the Electronic Products Program) at the Southwestern Radiological Health Laboratory (SWRHL) initiated a project for developing instrumentation and methods for field measurement of electromagnetic power levels in the frequency range of 54 to 220 MHz. An electromagnetic surveillance study was designed to obtain a profile of the electromagnetic radiations originating from selected transmitters operating in this frequency range in the metropolitan Las Vegas area. These transmitters are listed in appendix A. The purpose of this study was to determine if a predictable relationship exists between the experimentally observed and the theoretically calculated power levels from the above-mentioned transmitters. Demonstration of such a relationship would eliminate the need for elaborate field measurements in any given area to determine the actual power levels.

There are problems associated with the measurement of these low power density levels, especially for electromagnetic fields that are complicated by multipath interference or irregular terrain (5). Therefore, the measurement of electromagnetic energy is more complex than for optical radiation or ionizing radiations.

This report is divided into three sections. The first describes the experimental design of the study, including the development of instrumentation and methodology; the second discusses the effects of different environmental conditions on the data; and the final section compares the field measurement results with estimates derived from theoretical considerations.

## 2. INSTRUMENTATION AND METHODOLOGY

The first considerations in the experimental design of this project were the development of (1) appropriate instrumentation and (2) survey methods and techniques to provide a representative profile of the electromagnetic power levels in the metropolitan Las Vegas area.

In this study a calibrated Systron-Donner spectrum analyzer was used as the primary field measurement instrument. This instrument, which operates basically as a superhetrodyne receiver, has high sensitivity and a wideband display (up to 500 MHz) of the electromagnetic power distribution (in dB) as a function of frequency for the fundamental band of the analyzer. The analyzer is capable of power versus frequency measurements between 10 MHz and 6.5 GHz. The spectrum analyzer has external vertical and horizontal outputs for display on an x-y plotter. Also, an audio amplifier and speaker can be connected to the vertical output terminal for aural identification of a particular transmitter by using the manual sweep control and a proper combination of bandwidth and scan width control settings. A coaxial switch was used in the calibration procedures in order to rapidly and easily switch the inputs to the spectrum analyzer between the antenna cable and the calibrated VHF generator.

The instrumentation was mounted in a 17-foot Airstream trailer equipped with a 220V/110V propane motor-generator set and a three-section tower as shown in figure 1. Although the motor-generator set provided ample power and good regulation for both an air conditioner and the instrumentation, a Sorenson line-voltage regulator was used for the instrumentation rack only. A Polarad spectrum analyzer provided a system redundancy. A slotted line, mounted on the workbench, was used to determine the antenna transmission line characteristics. The field measurement instrumentation inside the trailer is shown in figure 2, and a general floor plan of the field measurements trailer in shown in figure 3.

An antenna rotator was attached to the top of the antenna tower to position the antenna in increments of 5 degrees for a complete rotation of 360 degrees. Because of the symmetrical design of the receiving antennas, however, the measurements at 180 degrees opposite a specific antenna orientation were identical. In addition to the antenna rotor position indicator, a servo transmitter was attached to the antenna shaft with the receiver servo position indicator inside the trailer, which also provided an indication of the antenna orientation.

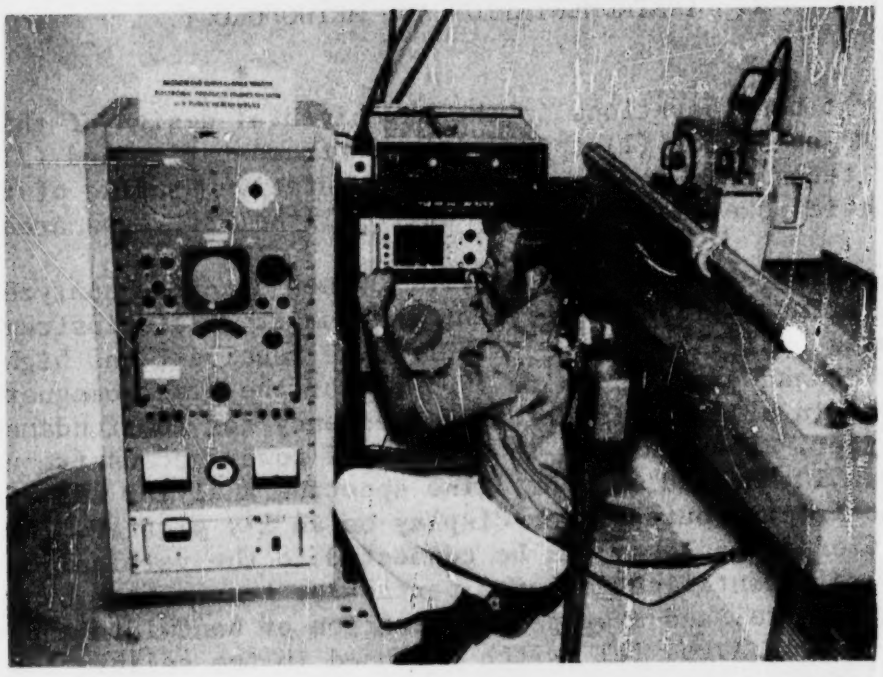


Figure 1. Field measurements trailer.

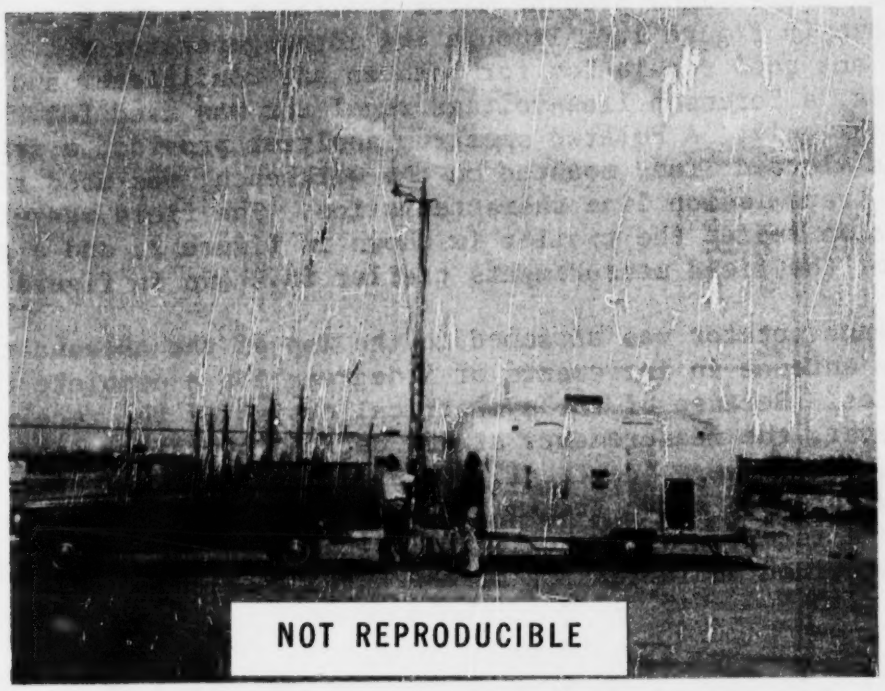



Figure 2. Field measurements instrumentation.

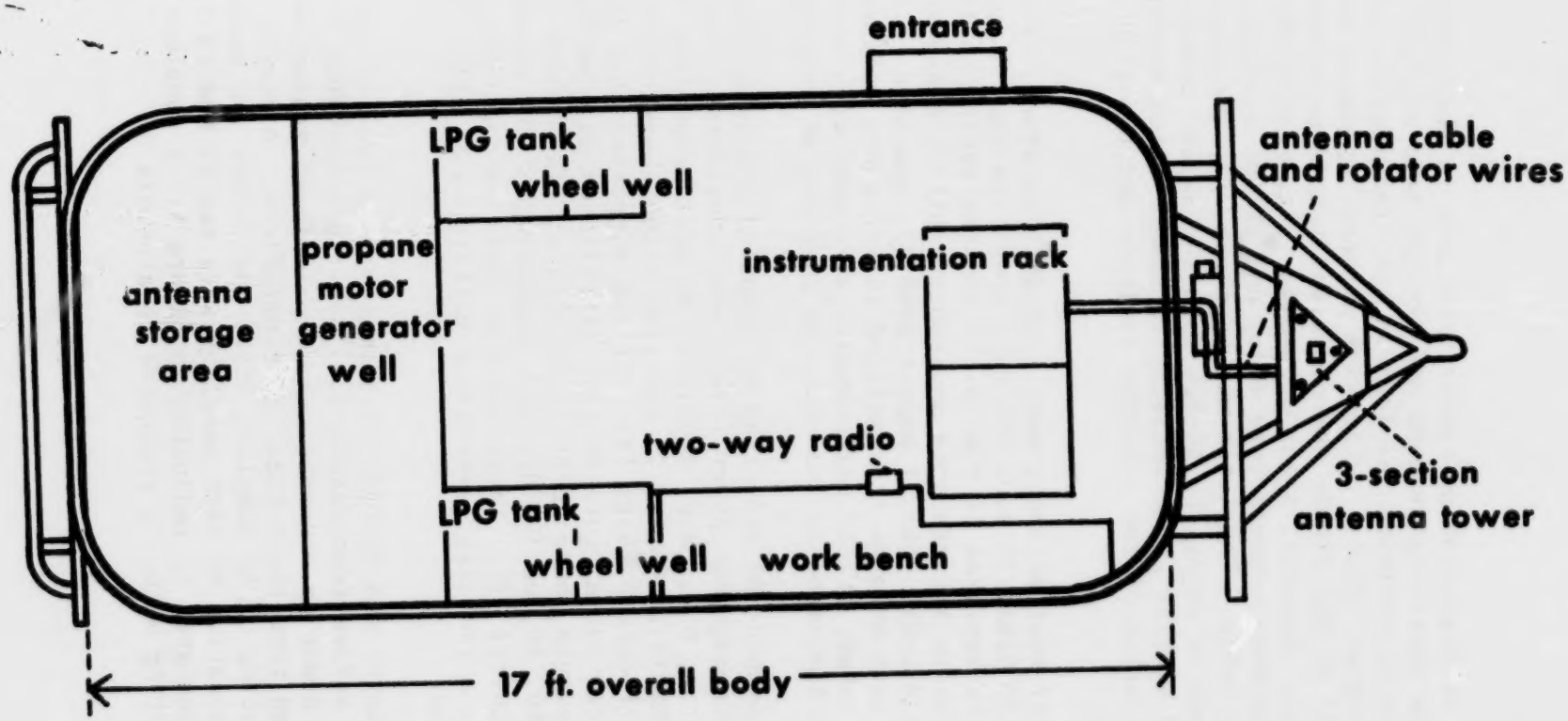



Figure 3. Floor plan of the field measurements trailer.

Two types of transmission cables were used in this study to interconnect the receiving antenna and the spectrum analyzer. Since it was desirable to minimize the loss in the transmission cable, a low-loss, rigid-foam helical cable with matched impedance connectors was chosen. All of the dipole antenna measurements were made with this rigid cable. However, signs of breaks in the cable were noted after the dipole measurements were made, and it was necessary to use a more flexible cable. The later measurements with the biconical antenna were made by using the RG-9/U double-shielded coaxial cable. Both cables had similar characteristic impedance which matched the input characteristics of the spectrum analyzer and the associated instrumentation.

Two military test antennas were used in this study. Military standard, MIL-STD 826A, 30 June 1966(6), specifies that a tuned dipole antenna be employed in the 35- to 200-MHz region as the test antenna for radiated interference and susceptibility measurements. A later standard, MIL-STD 461A, 1 August 1968(7), specifies a biconical antenna as the test antenna for radiated interference measurements in this frequency range. Field measurements were made with both types of antennas, as discussed in the next two sections of this report.

Next, the number and selection of sampling locations needed to assess the electromagnetic power levels were considered. One study made in Washington, D.C., area consisted of making spectrum signatures from 10 kHz to 10 GHz at 10 selected sites where humans would collect in significant numbers (8). It was suggested that the selection of sites for a given area be established on some basis of symmetry; for example, on concentric circles of 1/2- or 1-mile intervals every 45, 60, 90, or 120 degrees, depending on the number of measurements required (9). Since the Las Vegas metropolitan area is not organized in a radially symmetrical pattern, a slightly different approach was used.

Each television and FM radio transmitter was located and marked on a 7.5-minute series topographic U.S. Coast and Geodetic Survey (USC&GS) map in order to evaluate and compare field measurements with estimates derived from theoretical considerations. A nearly rectangular grid consisting of 62 sampling sites was chosen and marked on the same map. The location of each sampling site and TV and FM radio transmitter in the area is indicated in figure 4. A complete description of the sampling sites is presented in appendix B.

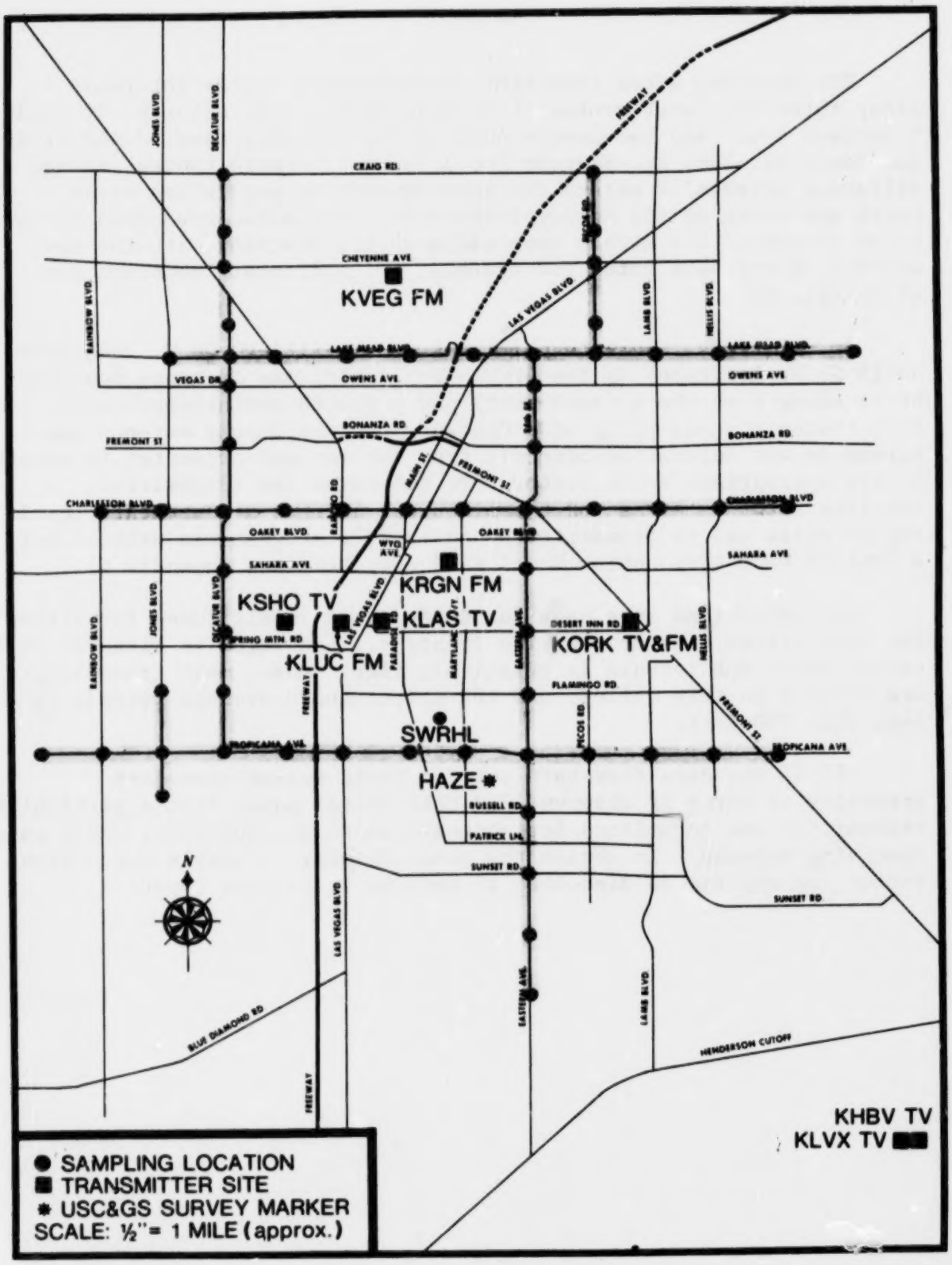



Figure 4. Sampling locations and transmitters.

The sampling sites represent approximately 1-mile intervals along three east-west routes (Lake Mead Blvd., Charleston Blvd., and Tropicana Ave.) and two north-south routes (Decatur Blvd.-Jones Blvd., and Pecos Rd.-25th St.-Eastern Ave.). The north-south routes include different streets to extend the measurements to population areas north and south of the metropolitan area. The sites are coded by the first letter of the street name and numbers, starting with the most western or northern site; for example, T-1 indicates Tropicana Ave. at Buffalo Dr.

An arbitrary reference point was chosen (115-00-00 W. longitude, 36-15-00 N. latitude) as the origin for making map distance measurements along both the x (east-west) and y (north-south) coordinates. Each transmitter-sampling site distance for the dipole antenna measurements was determined directly from the map and converted to meters by the appropriate scale factor. To determine the transmitter-sampling site distances for the biconical antenna measurements involving 62 sites and 14 transmitters, however, a program was written for a Control Data Corporation Model 6400 computer (see appendix C).

No corrections were made for differences in altitudes for either the transmitter site or sampling location. Las Vegas is situated in a valley where the terrain is relatively flat. Also, most transmitters are located in this valley, and the height above average terrain is less than 200 feet.

All of the data from both sets of field measurements are presented in terms of observed and theoretical power from a particular transmitter and normalized for convenience to an isotropic, unity gain, receiving antenna. To obtain the power density, a simple conversion factor was applied as discussed in section 5 of this report.

# 3. FIELD MEASUREMENTS WITH A DIPOLE ANTENNA

## 3.1 DIPOLE CONSTRUCTION AND CALIBRATION

A calibrated receiving antenna is necessary in order to make quantitative microwave field measurements. An antenna can be defined as a conductor or a series of conductors that serve to radiate or intercept electromagnetic energy in the form of electromagnetic waves. One type of antenna which was used is the dipole antenna. Each conductor on the dipole is chosen to be one-quarter of the free space wavelength, $\lambda/4$, corresponding to the generated transmitter wavelength for a total length of $\lambda/2$. If the dipole antenna is made of small-diameter conductors and is perfectly isolated in space, the antenna length corresponds closely to the actual physical length ($\lambda/2$). The antenna, however, is never completely isolated from surrounding objects. For example, the conductors are supported by insulators with dielectric constants greater than 1. Therefore, the velocity of the wave along the conductor is always less than the velocity in free space, and the length of the antenna is correspondingly greater (by about 5 percent) than the corresponding half-wavelength in free space.

A half-wave dipole antenna was constructed, as shown in figure 5, for optimum gain at 213 MHz (Television Channel 13) by cutting each of the elements physically to 1/4 wavelength. The antenna was then tuned to resonance at this frequency by trimming each of the elements by small amounts until a minimum standing-wave ratio was achieved. The resulting overall length was 0.95 times the freespace half-wavelength. The theoretical gain of this antenna over an isotropic antenna is 2.15 dB.

The military standard for electromagnetic interference test requirements, MIL-STD 826(6), states that a tuned dipole can be used for radiated interference tests and that a "tuned dipole can be tuned to a preselected fixed frequency with a correction factor applied to obtain equivalent meter readings at other frequencies." Therefore, one dipole antenna can be used for the entire spectrum of frequencies between 54 and 220 MHz with an appropriate calibration factor applied.

The calibration procedure consisted of comparing the Southwestern Radiological Health Laboratory dipole with the Scientific Atlanta standard-gain dipole antennas at the frequencies listed in table 1.

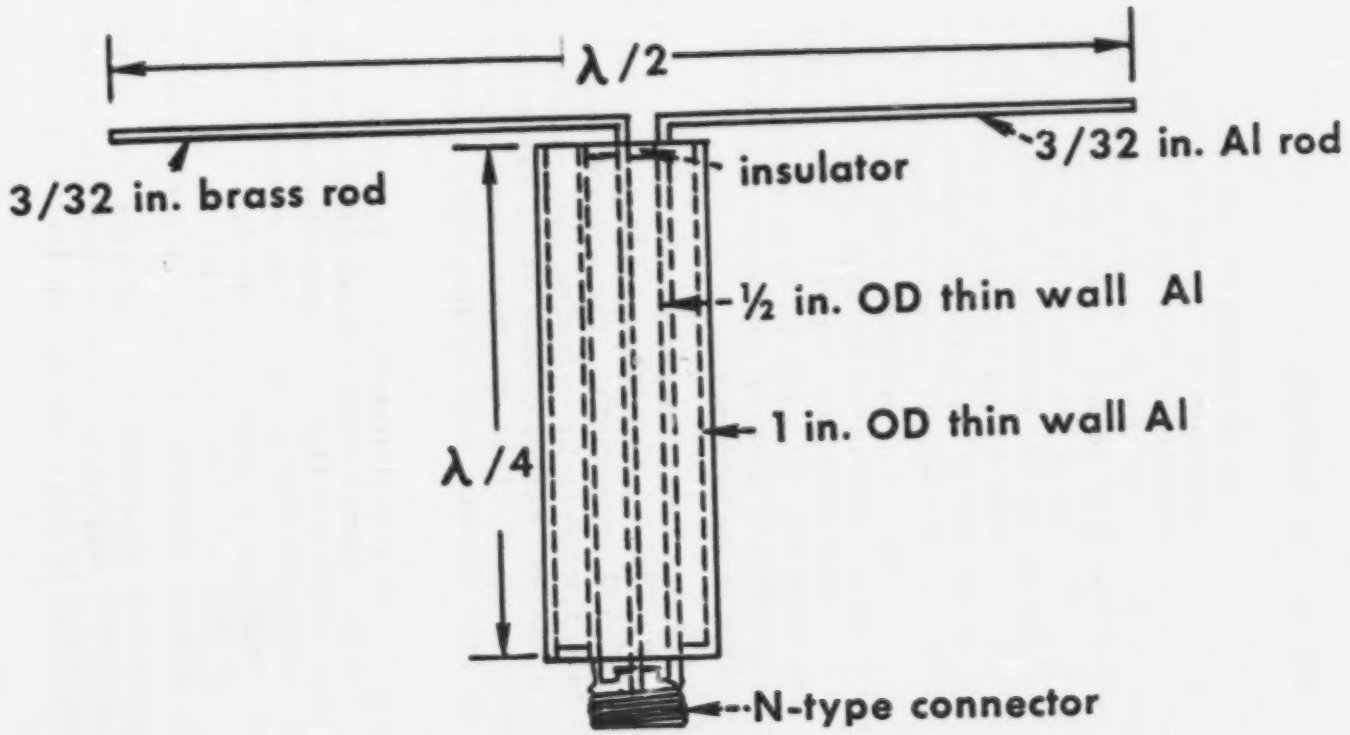



Figure 5. SWRHL dipole antenna.

Table 1. Frequencies used for dipole antenna calibration.

| Television[a] and FM radio transmitter frequencies in the Las Vegas area (MHz) | Frequencies used for the dipole antenna calibration (MHz) |
|---|---|
| 63 | 63 |
| 79 | 77 |
| 92.3 | 90 |
| 97.1 | 105 |
| 98.5 | 150 |
| 101.9 | 175 |
| 183 | 200 |
| 197 | 220 |
| 213 | |

[a]Center frequencies were selected for television transmitters.

An open field was chosen as the site for this procedure. The relative amplitude of the calibration signal at each frequency selected was determined on the spectrum analyzer using the SWRHL dipole antenna and the standard-gain dipole antennas for a constant transmitter output and the same antenna orientation. The measurements for each frequency were repeated, and the deviation between the two sets of measurements was within ± 1 dB. The average gain of the SWRHL dipole relative to the standard-gain dipole is referred to as the calibration factor and is shown in figure 6. The amplitude measurements for frequencies between 77 and 220 MHz could then be corrected and expressed in terms of the standard-gain antenna.

An expression for the effective gain for a dipole antenna is:

$$G = (P_d - P_{std}) + G_{std} \qquad (1)$$

where $P_d$ = Power received using a dipole (dB)

$P_{std}$ = power received using standard gain antenna (dB)

$G_{std}$ = gain of standard antenna (2.1 dB)

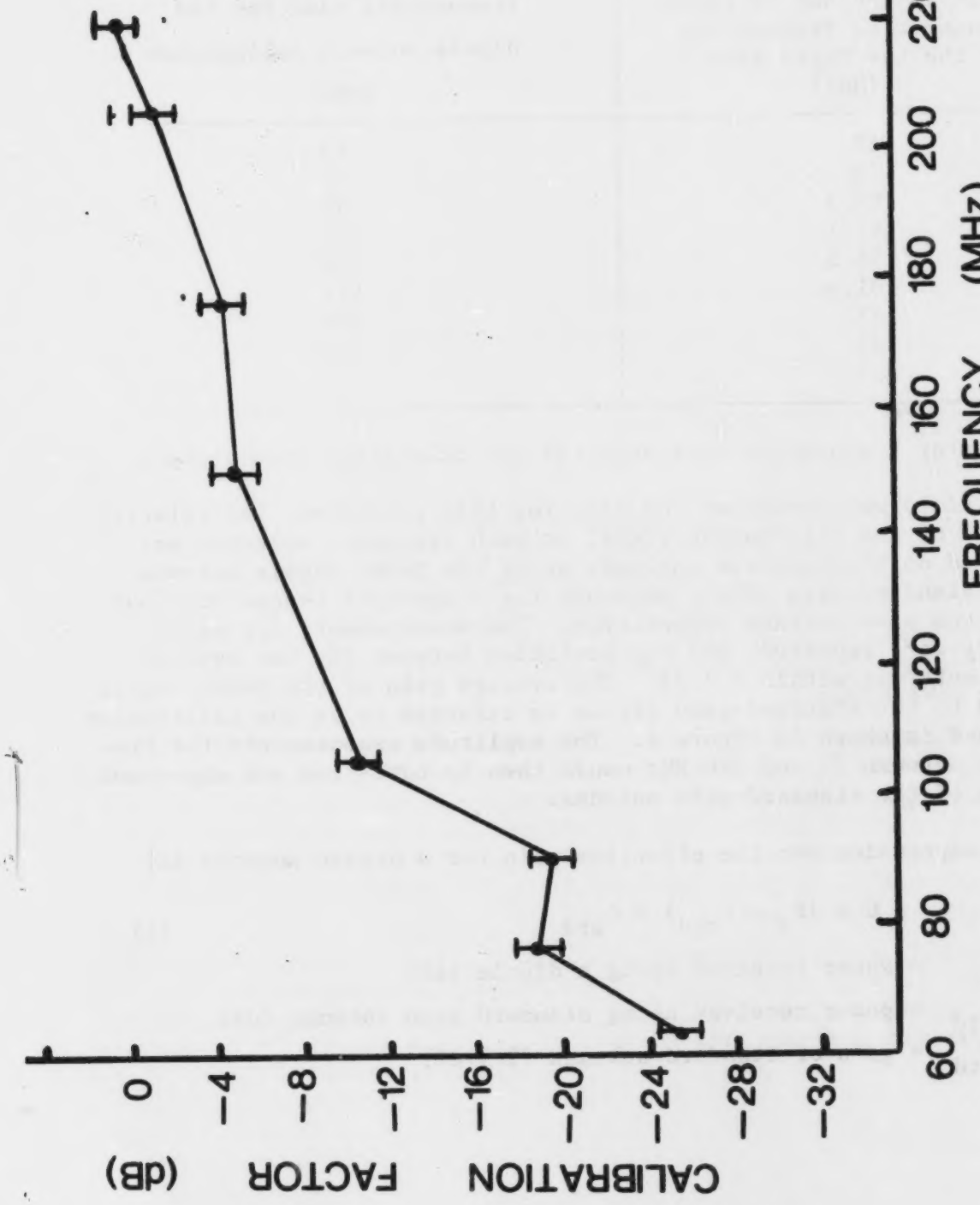



Figure 6. Calibration factor for SWRHL dipole antenna.

The observed power relative to an isotropic, unity-gain antenna can be determined by the expression

$$P_{obs} = \frac{P_d}{G} \qquad (2)$$

Another half-wave dipole was constructed and tuned for 63 MHz because the standard-gain dipole antennas were not calibrated below 77 MHz. This antenna became the necessary standard at 63 MHz. The expression for the theoretical calculated power from a transmitter at a particular grid point can be determined by the expression developed in more detail in section 4.7 of this report:

$$P_{calc} = \frac{P_t \lambda 2}{(4\pi)^2 r^2} \qquad (3)$$

where $P_t$ = effective radiated power of transmitter (watts)

$\lambda$ = wavelength (meters)

$r$ = distance from transmitter site to grid location (meters)

## 3.2 CALIBRATION OF SPECTRUM ANALYZER

A series of calibration measurements was made at a number of frequencies from 62 MHz to 220 MHz to determine the relationship between signal amplitude readings on the Systron-Donner spectrum analyzer and the actual power received. The signal generator output was coupled through the 50-foot helical coaxial cable and a 10-dB attenuator to the spectrum analyzer or the power meter as shown in figure 7. The Hewlett-Packard Type 354A RF attenuator was inserted to limit the amount of signal passing through to the spectrum analyzer and also to minimize VSWR effects.

The VHF signal generator was tuned to the frequency of interest, as shown in table 1, and its output adjusted to give the desired signal height on the spectrum analyzer. The desired signal heights would be typical of expected transmitter power levels. Immediately after the desired signal height on the spectrum analyzer was obtained, the same signal was applied to the power meter and the power corresponding to a given signal height was determined.

Figure 8, a plot of signal amplitude (in dB) versus power (in μW) at 105 MHz, is typical of the data obtained. The linearity of this curve indicates a direct relationship between the height measurements on the spectrum analyzer and the power being delivered to the analyzer.

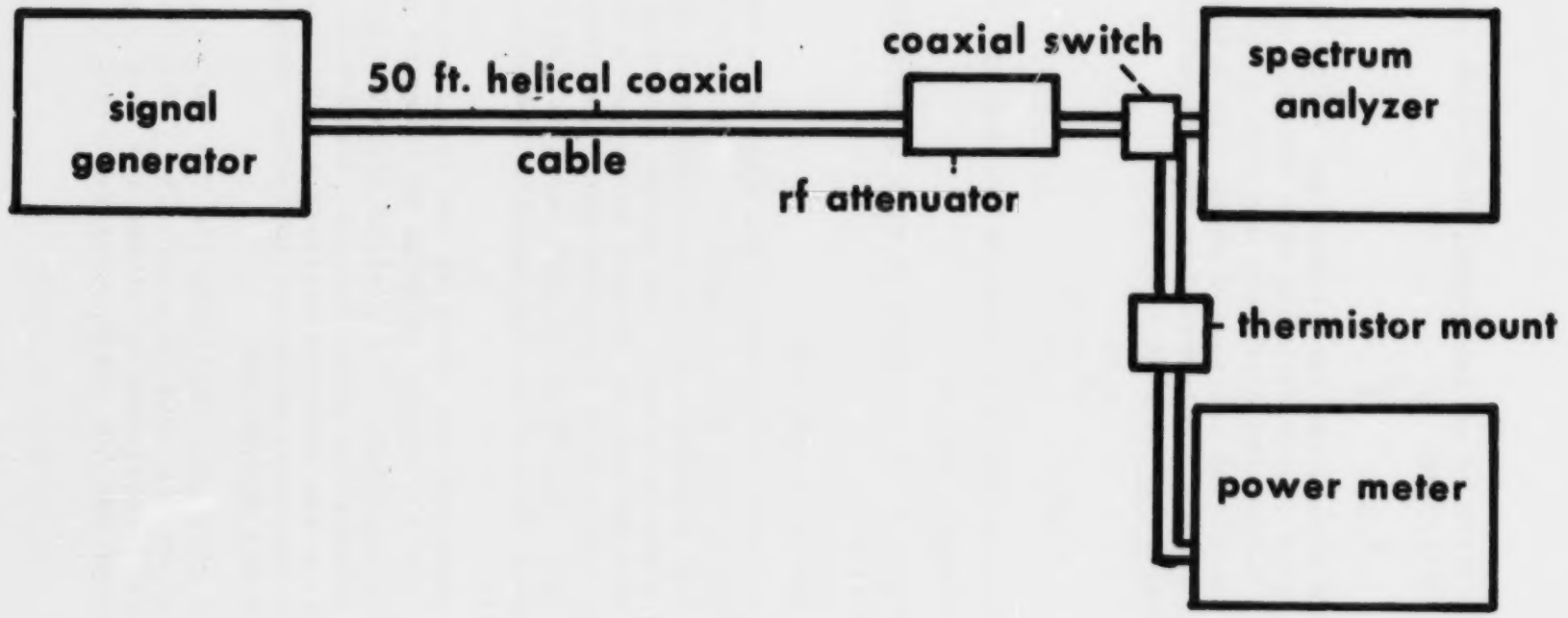



Figure 7. Comparison of spectrum analyzer and power meter measurements.

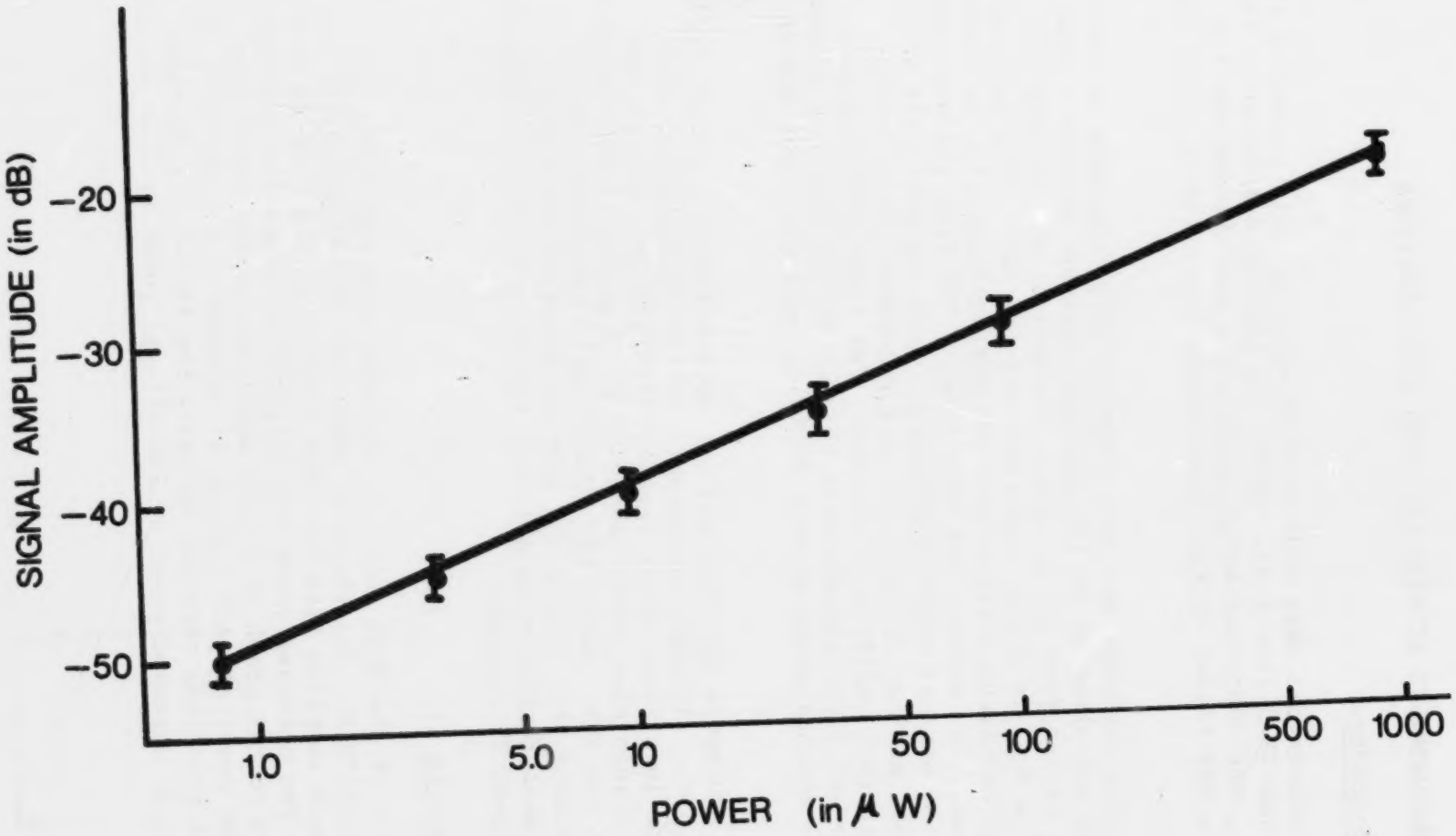



Figure 8. Signal amplitude versus power at 105 MHz.

## 3.3 FIELD MEASUREMENTS AT NINE SELECTED GRID LOCATIONS

### 3.3.1 Procedure

Field measurements were made at nine selected grid locations along Tropicana Avenue (T-1 thru T-9). After the trailer was moved to the sampling site, the instrumentation calibration was checked and the dipole antenna was raised to full mast height (10.3 meters above the ground).

The spectrum analyzer was then tuned to each frequency of interest, and the signal was observed on the spectrum analyzer display. When the frequency of interest was properly identified, the antenna was rotated until a null in signal amplitude was reached. This null indicated that the receiving antenna axis was perpendicular to the transmitting antenna. The antenna was then rotated 90° from the null position, giving the maximum signal amplitude. Both the amplitude of the signal in dB and antenna orientation were recorded. This antenna orientation was then verified on the map. For television stations, both the video and audio signals were present on the spectrum display; for the dipole antenna measurements, however, only the video amplitude was recorded.

The same procedure was followed for each television and FM radio signal on-the-air. Although the airport control frequencies were present at some locations, their transmission was intermittent and of much lower transmitter power (40 to 80 W) than the TV and FM transmitters (10 to 240 kW). Also, the educational television station (KLVX-TV) transmits only during the evening hours in the summer. Therefore, no measurements were made for the airport control frequencies or the educational TV channel.

### 3.3.2 Results

The results of the data taken at the nine sampling sites are recorded in appendix D. The observed power and calculated power are presented at each sampling site for four television and four FM radio transmitters. The observed power was obtained by comparing the signal amplitude in dB to the graph of signal amplitude versus power (fig. 8) to determine the power at each station of interest. The estimate of the theoretical power was obtained by using the formula in equation (3). The ratio of observed power to theoretical power is also included in appendix D.

# 4. FIELD MEASUREMENTS WITH A BICONICAL ANTENNA

## 4.1 CONSTRUCTION OF SWRHL BICONICAL ANTENNA AND BALUN

The biconical antenna was constructed according to the drawings in MIL-STD 461A, 1 August 1968. A biconical antenna is designed for military radiated emission measurements for the frequency range of 25 to 200 MHz. It was also necessary to construct a balun or antenna coupler to match this antenna to the characteristic impedance of the RG/9/U coaxial cable. The balun was constructed to meet the specifications in MIL-STD 461A.

In order to determine if the balun was functioning properly and had the desired electrical characteristics, it was compared with a borrowed Singer Metrics balun. The comparison procedure for the balun is the same as that previously described for the calibration of the SWRHL dipole (see section 3.1). The biconical elements were attached to the balun to be tested. The transmitting and receiving antennas were then aligned for maximum signal. Two series of measurements were taken at a number of frequencies between 60 and 220 MHz, using first the Singer balun and then the SWRHL balun in conjunction with the same biconical elements. Comparison of the two baluns indicated that the response of the SWRHL balun was electrically the same as that of the Singer Metrics balun. No more than 1 dB difference from 60 to 220 MHz was observed between the two baluns, which is well within the expected certainty of the system.

## 4.2 CALIBRATION OF SWRHL BICONICAL ANTENNA

The procedure followed in the calibration of the biconical antenna was the same as that described for the dipole antenna in section 3.2. The Scientific Atlanta standard-gain dipoles were attached to the trailer mast, and a series of measurements was taken at 11 different frequencies. A block diagram of the calibration arrangement is shown in figure 9.

At each frequency the amplitude of the signal (in dB) was measured for relative signal generator voltage settings of 3, 2, and 1 volts respectively. These relative voltage settings corresponded to the anticipated signal amplitudes at the sampling locations. Three readings were taken at each signal-generator setting to determine the average gain relative to the standard dipole, which is referred to as the "calibration factor." The graph of the calibration factor versus

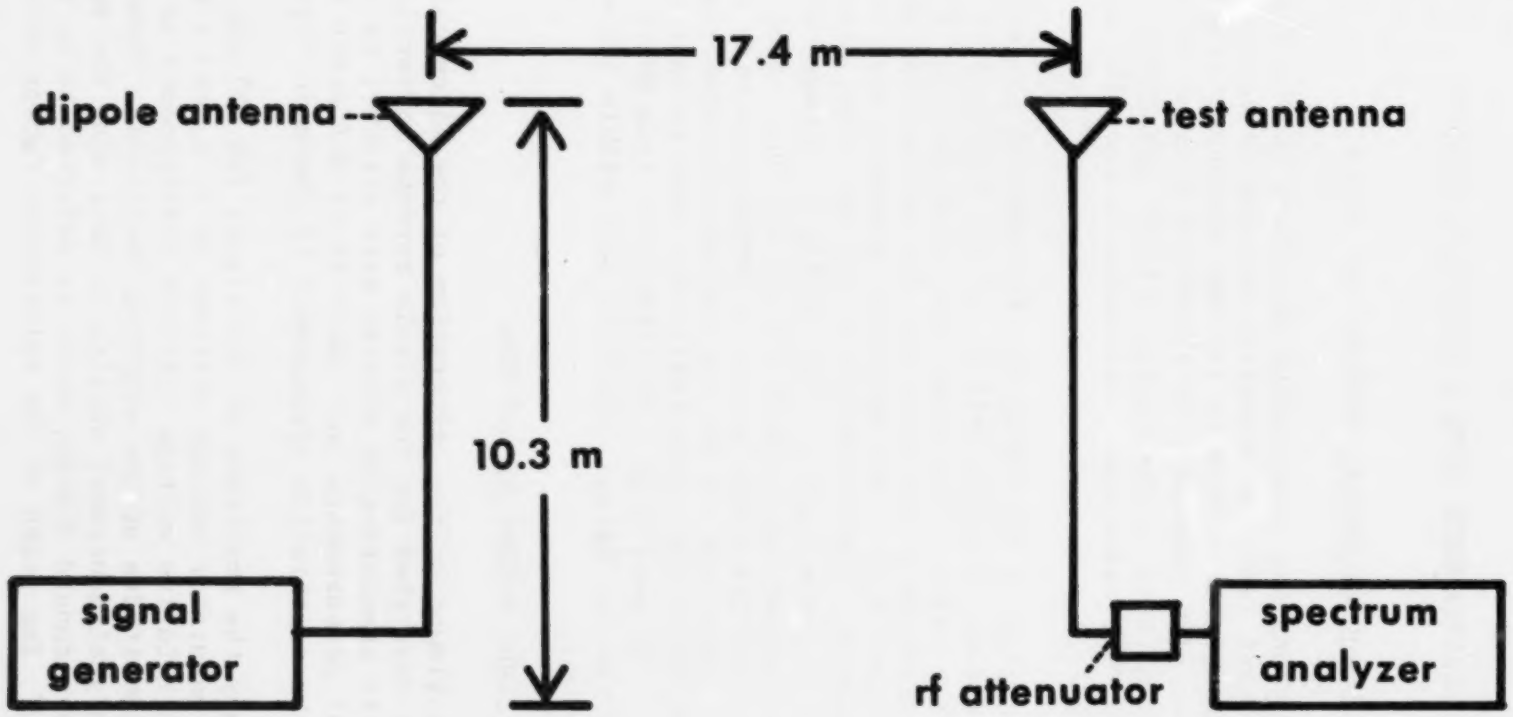



Figure 9. Calibration setup for test antenna.

frequency for the biconical antenna is shown in figure 10. Comparison of these data with the data obtained with the SWRHL dipole antenna indicated that the biconical antenna had a much higher gain at the lower frequencies which assisted the detection of low-level signals in the field measurements.

## 4.3 ANGULAR DEPENDENCE OF BICONICAL ANTENNA

A series of measurements was made in order to ascertain the effects of antenna position on signal strength. In making field measurements, it was found helpful to make two orthogonal antenna scans for the frequency range of interest and apply a correction factor for the angle between the receiving antenna and the transmitter. The typical angular dependence (i.e., KVEG-FM) closely (<1dB) approximates a 10 $\log_{10}$ ($\cos^2\theta$) function for angles less than $60^\circ$. The observed power variation and 10 $\log_{10}(\cos^2\theta)$ fit is shown in figure 11. For angles greater than $60^\circ$, the computer program used the orientation with the smaller angle (less than $30^\circ$). The computer program in appendix C was used to make the correction for angular dependence.

## 4.4 TWENTY-FOUR HOUR SURVEILLANCE

A 24-hour surveillance of the selected transmitters was made in order to determine the received power variation with time of day. Readings were made every 15 minutes with the spectrum analyzer and recorded on an x-y plotter for north-south and east-west antenna orientations. USC&GS survey location "Haze" was chosen because it was a relatively good reception area; i.e., flat terrain, easily accessible, and a well-defined elevation, latitude, and longitude (see fig. 4). All readings were corrected for analyzer drift.

The results of the 24-hour surveillance indicated an average variation of less than ±2 dBm over the 24-hour period for the five television and four FM radio transmitters monitored. The spectrum analyzer display can be read to ±1 dBm and the signal generator to an accuracy of ±1 dBm. Therefore, within the accuracy of the instrumentation used, there was negligible change in received power with time of day.

The Federal Communications Commission requires the radiated power to be within +10 percent and -20 percent of the licensed power. Conversations with local station managers indicated that the radiative power is normally within 2 percent of the licensed power.

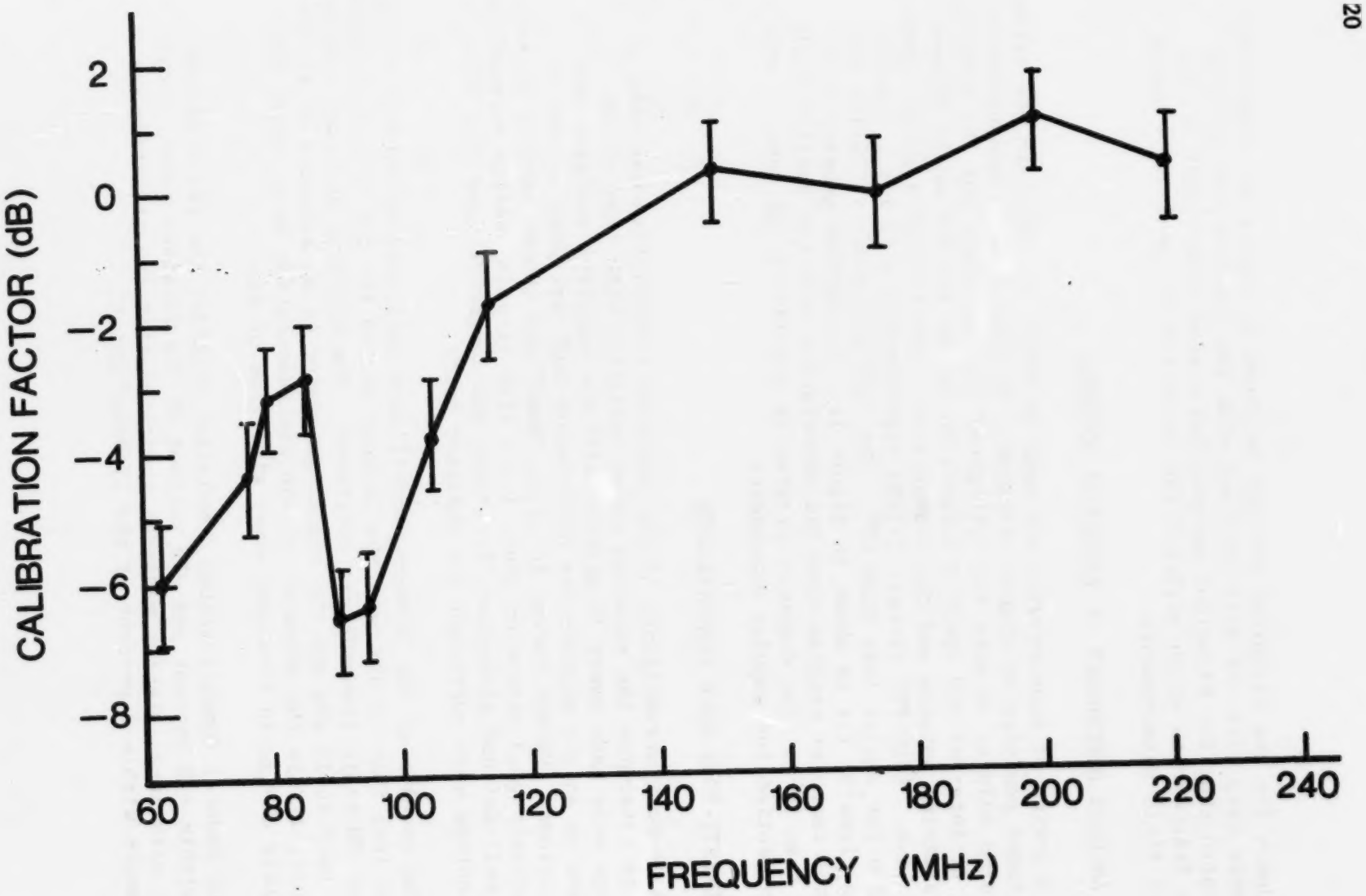



Figure 10. Calibration factor for SWRHL biconical antenna

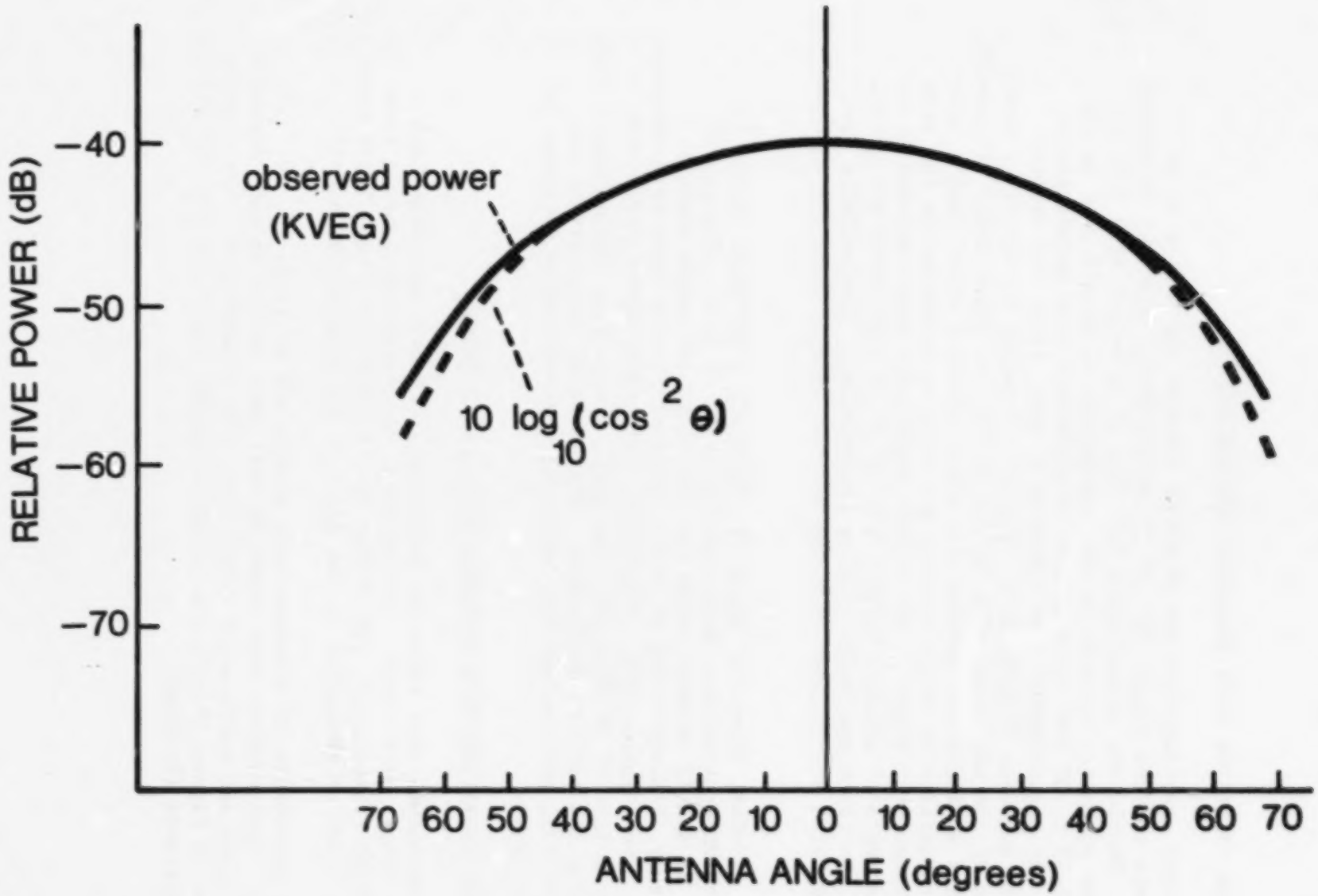



Figure 11. Relative power versus antenna angle.

## 4.5 POWER VARIATION WITH RECEIVING ANTENNA HEIGHT

Another consideration was directed towards the choice of an appropriate antenna height for taking measurements with the biconical antenna. Should the measurements be taken at a height of 6 feet to assess the potential hazards to the population or should they be recorded at 25 or 30 feet to minimize interference from ground plane effects? If measurements were taken at 6 feet, would the results provide an accurate indication of hazards to people in two-story homes or in one of the many high-rise hotels in the Las Vegas Area? To assist in making a decision, a location was chosen about 2 miles from a television transmitter on level terrain and with no obstacles in the path of the transmitted signal. The signal amplitudes were recorded at 1-foot increments of antenna height from 16 to 34 feet above the ground for both the video and audio carrier frequencies. Measurements were also taken at 6 and 10 feet with the antenna removed from the antenna tower.

The results, shown in figure 12, indicate a definite change in power with antenna height, particularly up to 16 feet. Changes in power of 11 and 12 dB were noted for the video and audio signals, respectively, between 6 and 34 feet. Similar results have been observed by other investigators(10). Therefore, all measurements were taken at full mast height of 34 feet (10.3 meters), since these measurements were more stable and readily obtainable. The measured power levels are greater at full mast height but represent a conservative estimate for hazard analysis.

## 4.6 POWER VARIATION WITH DISTANCE FROM A GRID POINT

Measurements were taken to determine the power variation with distance from a grid point. A flat area, approximately 2 miles from a television transmitter, was chosen as the sampling site. There were no power lines or obstacles in the path of the transmitter signal.

Log increments of distance were marked off at 1, 3, 10, 30, ... 600 feet. Measurements were taken at full mast height at each distance for the video and audio power level from this transmitter. The results are shown in figure 13 with the relative signal amplitude (in dB) plotted versus distance (in feet).

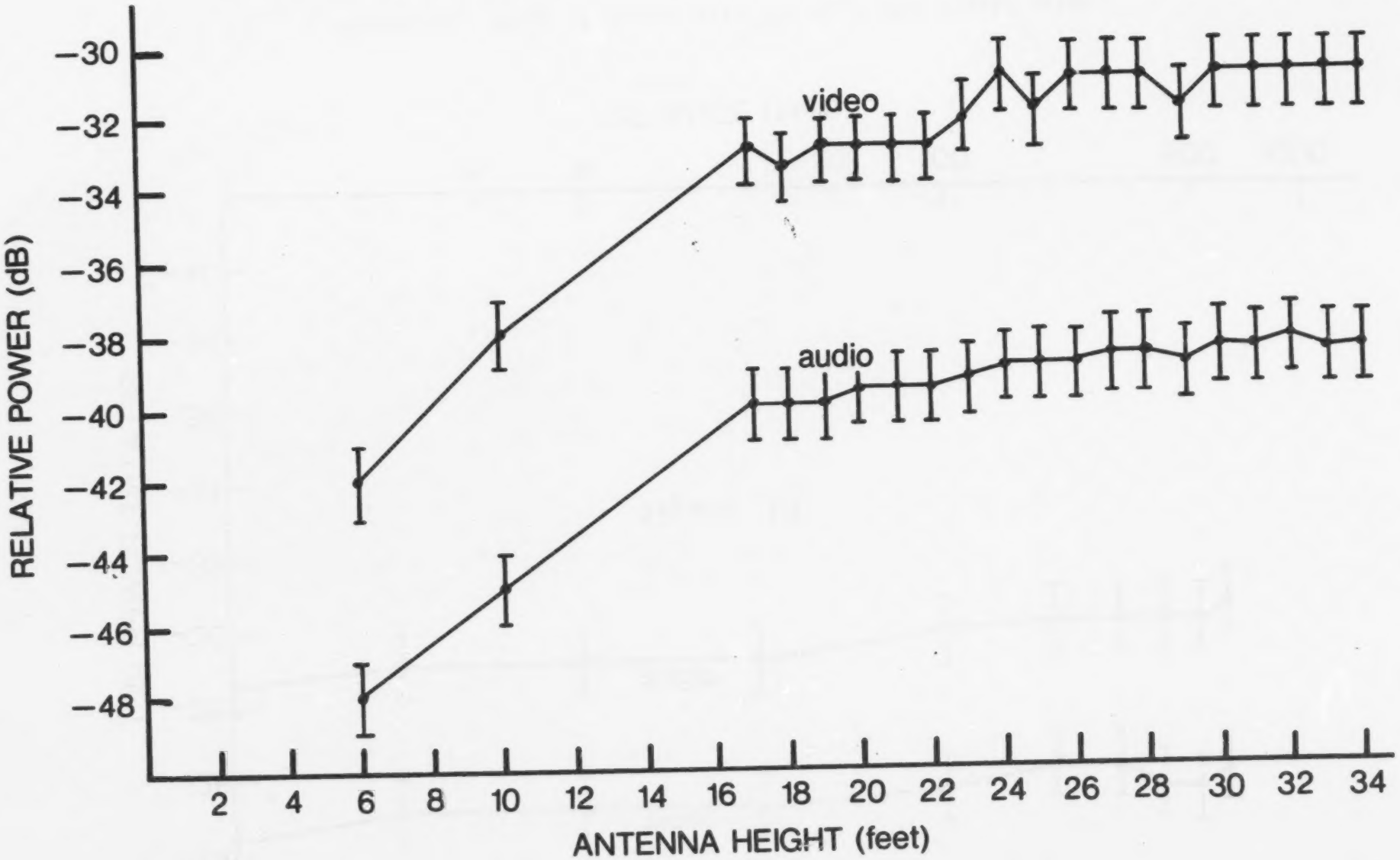



Figure 12. Relative power versus antenna height.

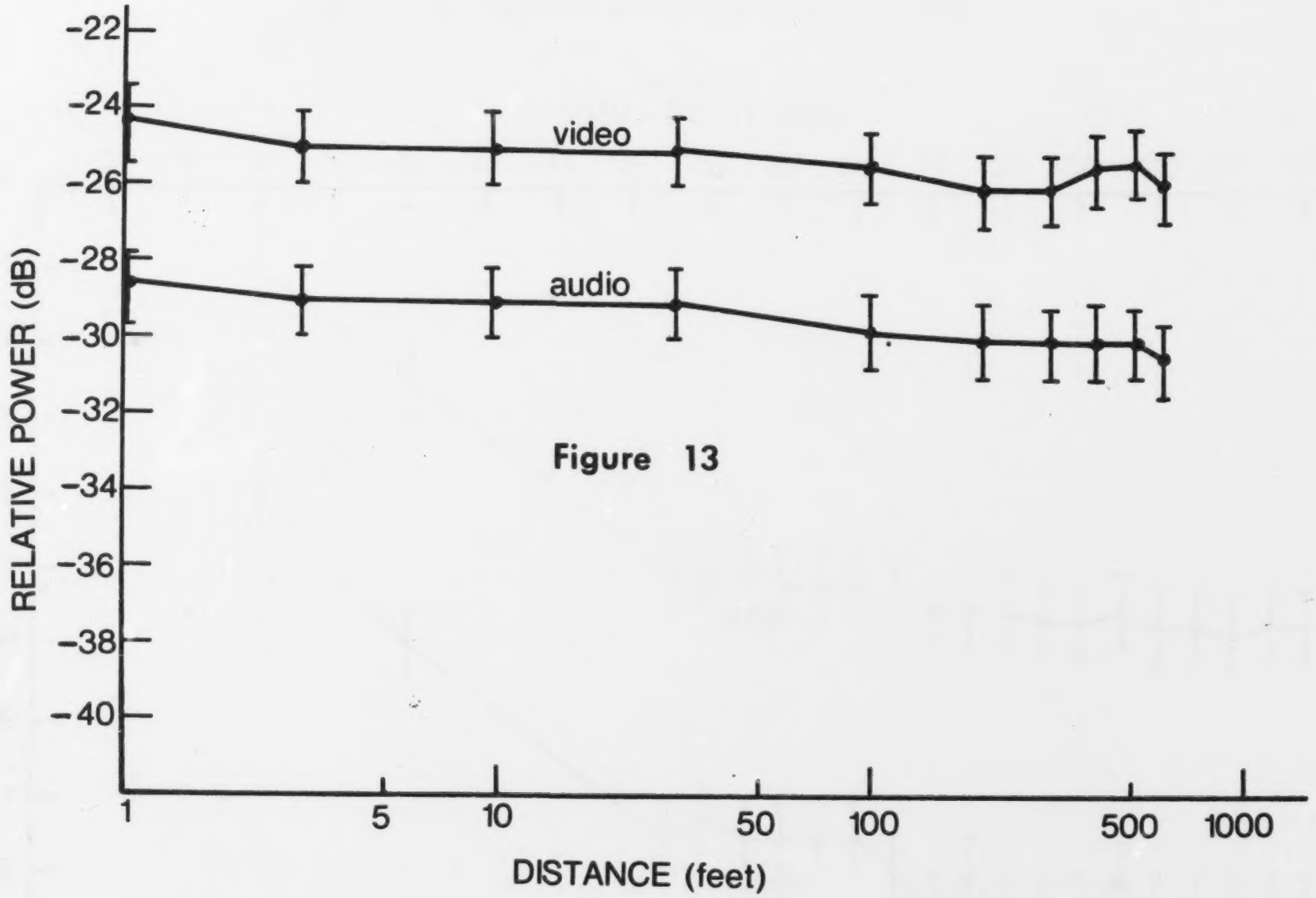



**Figure 13**

Figure 13. Power variation with distance from a grid point.

The measurements indicate that the power levels do not change abruptly with distance about a grid point. The sampling location on the USC&GS map can be determined very closely, and the theoretical power levels are derived from the actual coordinates of the measurements trailer location.

## 4.7 FIELD MEASUREMENTS AT 62 GRID LOCATIONS

### 4.7.1 Procedure

The field measurement procedures used for the biconical antenna were similar to the measurement procedures for the dipole antenna, as described in section 3.3. However, instead of tuning the spectrum analyzer to each station of interest as in the dipole measurements, two orthogonal scans were recorded on an x-y plotter at each sampling site. A scan was recorded for both the north-south antenna orientation and the east-west antenna orientation.

The sampling sites chosen were primarily on east-west and north-south streets. Therefore, an observer outside the trailer could visually align the antenna to within less than 10 degrees of the desired true orientation (fig. 11). A typical day's field measurements schedule is shown below.

Field Measurements Schedule

| Time | Activity |
|---|---|
| 8:00 - 8:30 a.m. | Start propane generator in trailer, turn on instrumentation, and proceed to sampling site. |
| 8:30 - 9:30 a.m. | Set up biconical antenna at sampling site and run up antenna to full mast height(10.3 meters). Calibrate spectrum analyzer and x-y recorder. |
| 9:00 a.m. - 3:30 p.m. | Record scan of frequencies up to 250 MHz for the east-west antenna orientation on the x-y plotter. By using the coaxial switch, record a 150-MHz calibration signal of -30 dBm on the same scan.<br><br>Repeat the same procedure for the north-south orientation. Run down mast, remove antenna, and proceed to next sampling site. (Repeat above procedure including the calibration of the x-y plotter at each sampling site). |
| 3:30 - 4:00 p.m. | Return to laboratory. Check all data |

To reduce systematic error, the same person performed the calibrations and recorded the data. A second person raised and lowered the antenna and assisted in orienting the antenna to the two orthogonal orientations. Usually one route (12 locations) could be completed in one day by two persons. A block diagram of the field measurements instrumentaion incorporating the biconical antenna is shown in figure 14.

### 4.7.2 Results and Calculations of Theoretical Power

The results of the field measurements made at the 62 sampling sites with a biconical antenna are tabulated in appendix E. Four values are presented at each sampling site for each transmitter of interest. They are the observed power (in μW), the calculated power (in μW), the ratio of observed power to calculated power, and the distance (in meters) between the sampling site and the transmitter site. The observed and calculated power values are printed out in E format notation (base 10); for example, 2.83 E+02 = $2.8 \times 10^2 = 283$ microwatts.

The three primary factors necessary to calculate the theoretical received power at an arbitrary location are the transmitted power, the distance from the transmitter to the arbitrary location, and the gain of the receiving antenna. The transmitted power or ERP (effective radiated power) was obtained by calling the station manager. ERP could also be obtained by listening to the signoff message or by contacting the FCC Frequency Allocation and Treaty Division in Washington, D.C. The distance was determined on the computer from the x and y coordinates on the USC&GS map (see section 2). The gain of the receiving antenna was determined by calibrating it against the standard-gain dipole antennas at each frequency of interest, as described in sections 3.1 and 4.2. If the arbitrary location is located in irregular terrain, additional factors, such as terrain cluster, antenna heights, angles to near- and far-field obstacles, the nature of terrain irregularity, and the depolarization of the signals must be considered.

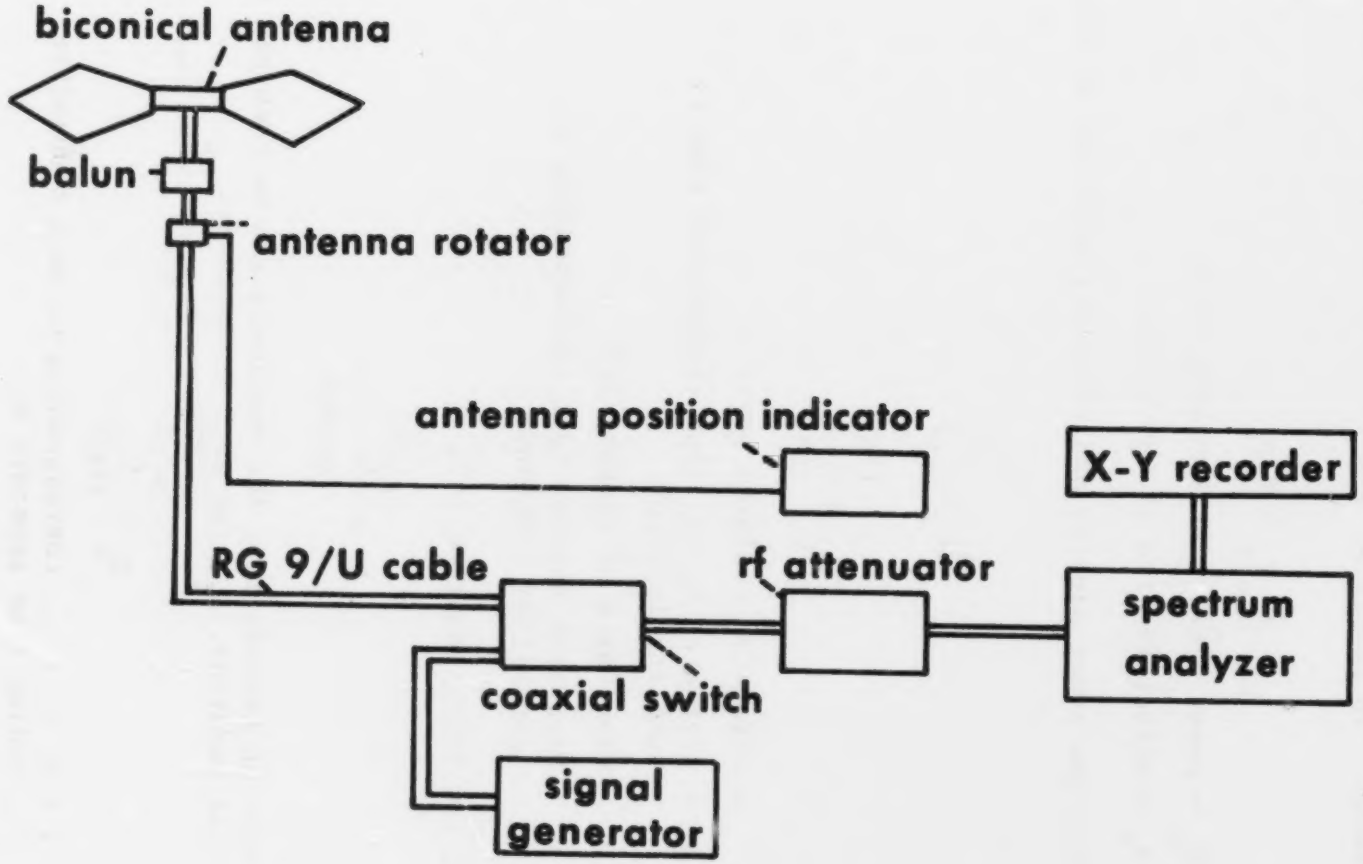



Figure 14. Block diagram of field measurement instrumentation.

The relationship used for determining the power received ($P_r$) and a sample calculation for a particular transmitter and grid point are shown below. In practice, the calculations are performed by the computer.

$$P_r = P_d A_e \tag{4}$$

where $P_d$ = power density at sampling point

$A_e$ = effective area of the antenna

However, the power density and effective area can be rewritten as:

$$P_d = \frac{P_t}{4\pi r^2} \tag{5}$$

and

$$A_e = \frac{\lambda^2 G_i}{4\pi} \tag{6}$$

where $P_t$ = effective radiated power

$r$ = distance, in cm, from transmitter site to sampling location

$\lambda$ = wavelength of transmitter

$G_i$ = biconical antenna gain corresponding to transmitter frequency

Then, rewriting equation (4),

$$P_r = \frac{P_t \lambda^2 G_i}{(4\pi)^2 r^2} \tag{7}$$

For ease in calculation, the constants can be combined to yield a transmitter constant, $K_i$, for each transmitter:

$$K_i = \frac{P_t \lambda^2}{(4\pi)^2} \tag{8}$$

where $i$ = 0, 1, 2 ... corresponding to each transmitter coding (see appendix B)

Therefore, equation (7) can be simplified to the following:

$$P_r = \frac{K_i G_i}{r^2} \tag{9}$$

It is assumed that free-space propogation exists, that the distance (r) will be in the far field, and that the power changes as the inverse square of the distance from the radiative source.

A sample calculation for the power received at the SWHRL compound designated X-1 for transmitter code 8 (KSHO-TV Channel 13 video) follows.

$$P_t = 2.04 \times 10^5 \text{ W}$$
$$f = 211.25 \text{ MHz}$$
$$\lambda = c/f = 3 \times 10^{10} \text{ cm sec}^{-1}/211.25 \text{ MHz}$$
$$= 1.42 \times 10^2 \text{ cm}$$
$$G_8 = 1.90$$
$$r = 4.715 \times 10^5 \text{ cm}$$

Rewriting equation (8) for transmitter code 8 yields:

$$K_8 = \frac{P_t \lambda^2}{(4\pi)^2} = \frac{(2.04 \times 10^5 \text{ W})(2.02 \times 10^4 \text{ cm}^2)}{(4\pi)^2}$$

$$= 2.61 \times 10^7 \text{ W/cm}^2 \tag{10}$$

Therefore,

$$P_r = \frac{K_8 G_8}{r^2} = \frac{(2.61 \times 10^7 \text{ W/cm}^2)(1.90)}{(4.715 \times 10^5 \text{ cm})^2}$$

$$= 222.71 \text{ } \mu\text{W} \tag{11}$$

Relating this power received to an isotropic radiator to place the radiated energy on an absolute basis yields:

$$P_{calc} = \frac{222.71}{1.90} = 117.2 \text{ } \mu\text{W} \tag{12}$$

## 5. OBSERVED POWER DENSITIES

In the previous sections all calculations were based on the power as displayed by the spectrum analyzer. For considerations of biological effects, however, it is convenient to use units of power incident per unit area or power density. These values are obtained from the observed power levels by rewriting equation (4).

$$P_d = P_r \times A_e^{-1} \tag{13}$$

where $P_r$ = power received

$A_e$ = effective aperture (area) of the antenna

The effective aperture (area) of the antenna is calculated from the equation (6).

$$A_e = \frac{\lambda^2 G}{4\pi} \tag{14}$$

where $\lambda$ = free-space wavelength

$G$ = power gain of the antenna

Since two antennas were used in the course of the experimental investigations, two separate tables are presented listing the observed power densities as a function of the transmitter (source) and sampling site. Data derived from the SWRHL dipole antenna measurements are presented in appendix F, and the data derived from the biconical antenna measurements are presented in appendix G.

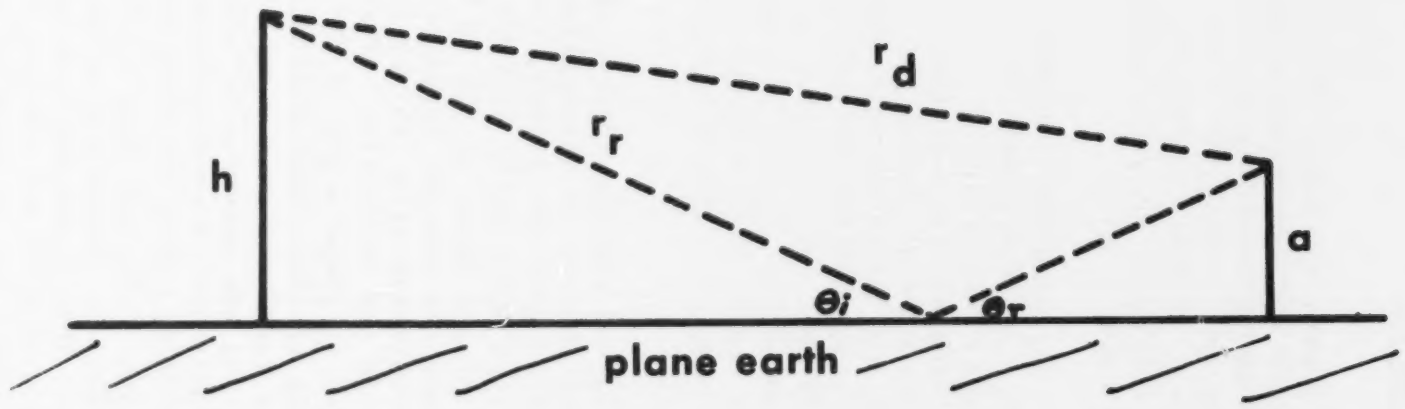
While the biological significance of such a value is highly uncertain, a last column showing the sum of the observed power densities at each sampling point has been included in appendixes F and G. The reader is left to make his own estimate of the usefulness of such a number.

# 6. DISCUSSION

The observed power, theoretical power, and ratio of observed to theoretical power are presented for both the dipole measurements (appendix D) and the biconical measurements (appendix E). For most transmitters the observed power at the grid points was lower than the theoretical power. This may be a result of the interference and attenuation of the transmitted power caused by buildings, power lines, uneven terrain, and other obstacles in the beam.

Power lines are an effective carrier of electromagnetic signals for the frequency range in this study. In some areas, if power lines were near the test antenna, the antenna orientation for maximum signal was not that of the axis of the receiving antenna pattern; instead, the antenna orientation was between the axis of the antenna pattern and the power lines. Therefore, sampling locations near power lines were avoided as much as possible by either moving the trailer to the other side of the street or moving 100 feet away from the intersection. Specific examples of grid locations where power lines may have a considerable effect were T-6, C-10, C-11, L-11, L-12, and E-2. The ratio of observed to theoretical power at these locations are larger than at similar sites with no power lines nearby.

Other factors that must be considered are the effects of terrain on propagation. The primary effect of terrain on propagation is that part of the energy radiated is reflected from the ground, forming a reflected wave (or waves) which combines vectorially with the direct or free-space wave. The field strength at any point is the vector sum of the two components: the direct wave and the wave(s) reflected from the surface. If a flat-plane earth is considered (fig. 15) by the geometry of propagation, the angles of incidence and reflection of the reflected paths cause a corresponding difference in phase angle as they combine at the receiving antenna. As a result of this phase shift, the direct and reflected waves tend to cancel or reinforce each other. If one parameter, such as distance or height of one antenna, is varied and the other parameters remain fixed, alternate cycles or reinforcement and cancellation will occur. This was observed when the receiving antenna height was varied above ground (section 4.5), and when the distance was varied from a grid point (section 4.6). At larger distances and with the antennas near the ground, however, this phase shift should be relatively constant. Reflections from terrain and terrain clutter (buildings, etc.) can also produce changes in the plane of polarization which will affect the power received. All field measurements were taken with horizontally-polarized antennas.




h is the height of transmitter
a is the height of antenna
$r_d$ is the direct propagation path
$r_r$ is the reflected propagation path
$\theta_i$ is the incident angle
$\theta_r$ is the reflected angle

Figure 15. Direct and reflected propagation paths for electromagnetic signals on a plane earth.

A scatter plot is shown in figure 16 for the observed versus theoretical power for the dipole antenna measurements. The plot shows that 95 percent of the observations are within a variation of -10 dB to +2 dB from the theoretical levels. The greater variations from the theoretical power levels occur at the lower power levels.

The biconical antenna measurements were taken at greater transmitter-sampling site distances than the distances used for the dipole antenna measurements. Figure 17 is a scatter plot of observed versus theoretical power levels for transmitter KSHO-TV (video) using the biconical antenna. The plot shows that 95 percent of the observations are within a variation of -17 dB to +2 dB from the theoretical power levels. This variation is greater than the variation for the dipole measurements, indicating that an accurately calibrated, tuned, dipole antenna would provide a lower system error. A linear regression line is included in both figures 16 and 17.

A graph was also plotted for the ratio of observed to theoretical power levels versus distance for the same transmitter KSHO-TV (video) (fig. 18). The ratio varies between approximately 0.02 and 1.6 for the 62 grid points. At the distances closer to the transmitter (less than 2500 meters) the observed power was much lower than the theoretical power. This may be attributed to the field distribution pattern of the transmitting antenna. At distances greater than 2500 meters there is a wide variation in ratios, indicating that the received power cannot be accurately calculated by distance alone.

The total observed power density at each location from the selected transmitters is presented in appendixes F and G. The largest location total was 813 $nW/cm^2$ or 0.813 $\mu W/cm^2$. This is lower than the levels observed in the Washington, D.C., area study where values exceeding 100 $\mu W/cm^2$ at certain locations were noted for a spectrum surveillance up to 10 GHz.

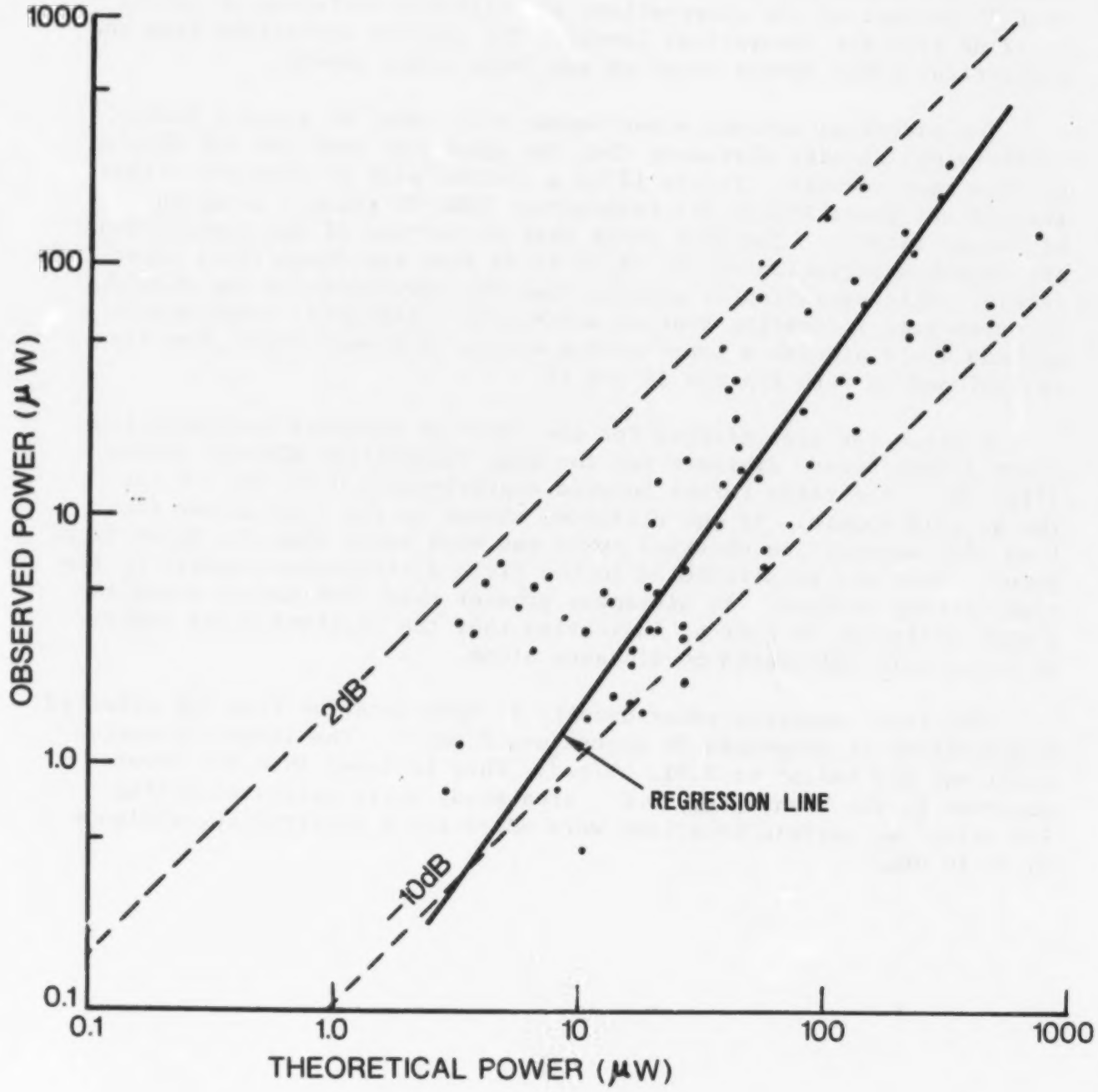



Figure 16. Observed versus theoretical power for SWRHL dipole antenna measurements.

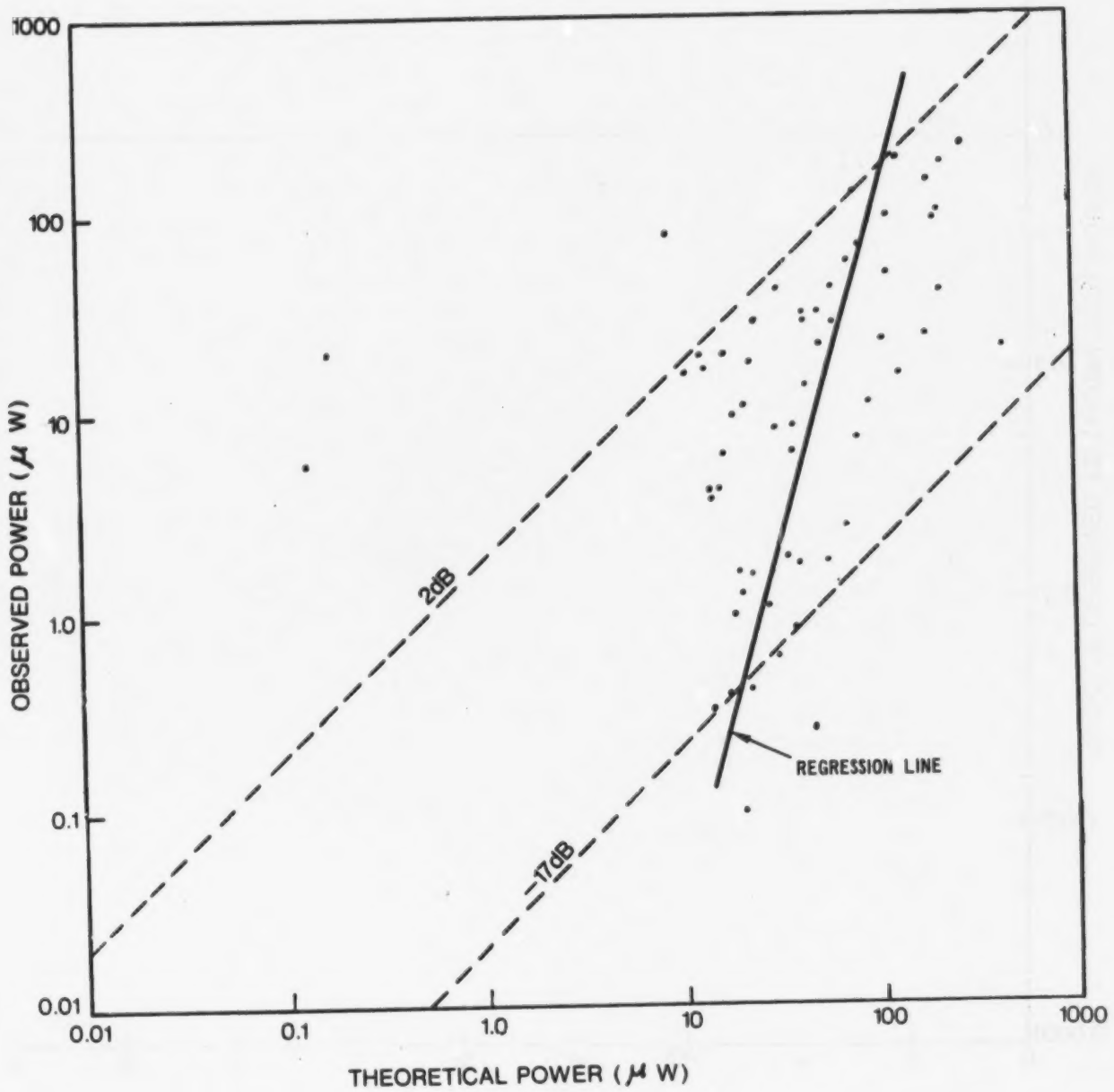



Figure 17. Observed versus theoretical power for KSHO-TV (video), measured with biconical antenna.

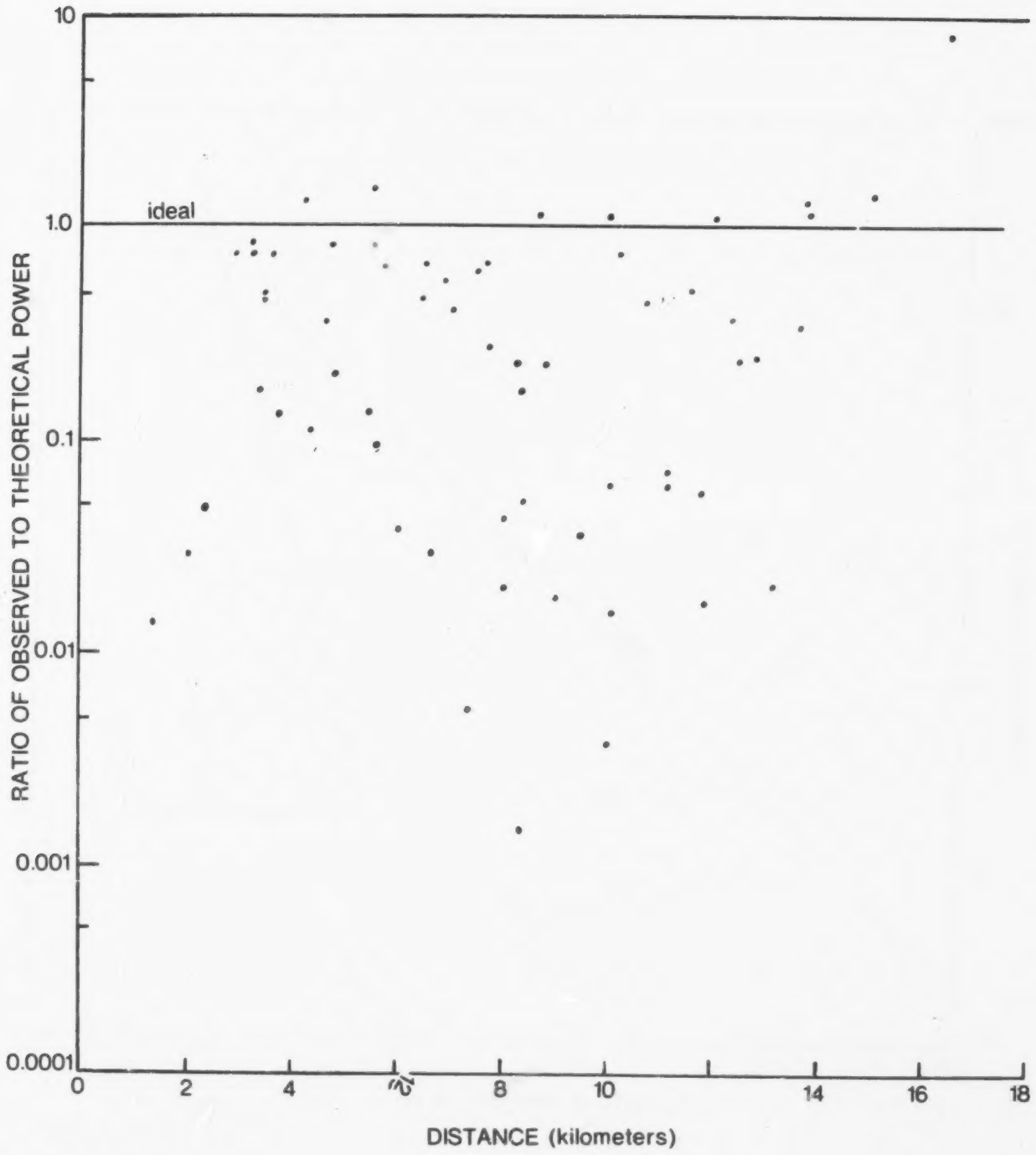



Figure 18. Ratio of observed to theoretical power versus distance for KSHO-TV (video).

## 7. CONCLUSIONS

Factors considered in the design of this study included the equipment, the antenna calibration, the power variation with antenna height, the time of day, the distance from a grid point, and the antenna angular dependence required to obtain a representative profile of electromagnetic power levels with a preselected frequency interval in a given area. The results of the actual field measurements indicate that:

(1) There is a relationship between the results of field measurements and the estimates of theoretical power levels in the Las Vegas area for the frequency range of 54 to 220 MHz.

(2) At a confidence level of 95 percent, one can expect measured power levels to vary from the calculated levels by -10 to +2 dB.

(3) The actual observed power at the 62 selected grid locations was in most cases lower than the theoretical power. This may be attributed to the irregular terrain, obstacles such as buildings in the path of the beam, or atmospheric attenuation (non-free-space conditions).

(4) A few observed values were larger than the theoretical power. As described in section 5, power lines near a particular grid point acted as a directive antenna element for some transmitters, resulting in a larger observed power. Also, the larger observed values may be caused by the reinforcement from the reflected wave combining at the antenna in phase with the direct wave.

(5) System errors seemed lower when a well-designed and calibrated dipole antenna was used rather than the MIL-STD biconical antenna. Future measurements should be made with appropriate dipole antennae, calibrated and matched at the frequency of interest.

In considering the possible biological hazards associated with these microwave power levels, observed differences will, in general, be on the conservative side when compared to the theoretical levels. An additional conservative factor is provided by the choice of antenna height. The power levels observed at 6 feet were lower than those measured at 34 feet.

Theoretical power levels could serve in lieu of extensive field measurements as a satisfactory measure of population exposure to electromagnetic energy in the frequency range considered, if one can accept the range of variation between observed and theoretical levels.

## REFERENCES

(1) PUBLIC LAW 90-602, 90th CONGRESS, HR 10790. Radiation Control for Health and Safety Act of 1968. Washington, D.C. (October 18, 1968).

(2) DEPARTMENT OF DEFENSE, ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER, ANNAPOLIS, MD., AND BUREAU OF RADIOLOGICAL HEALTH, PHS, USDHEW. A Partial Inventory of Microwave Towers, Broadcasting Transmitters, and Fixed Radar by States and Regions. BRH/DEP 70-15, Rockville, Md. (June 1970). (Available from National Technical Information Service, Springfield, Va. 22151 - PB 193 542, $3.00 for paper copy, $0.95 for microfiche).

(3) BUREAU OF RADIOLOGICAL HEALTH. Annual Report to the Congress on the Administration of the Radiation Control for Health and Safety Act of 1968 - Public Law 90-602. Rockville, Md. (April 1, 1970).

(4) FEDERAL COMMUNICATIONS COMMISSION. Computer Printout of Transmitters Operating Between 54 and 220 MHz in the Las Vegas, Nevada, Area. Frequency Allocation and Treaty Division, FCC, Washington, D.C.

(5) BOWMAN, RONALD R. Quantifying Hazardous Electromagnetic Fields: Practical Considerations. Technical Note 389, National Bureau of Standards, Boulder, Colo. (April 1970).

(6) MIL-STD-826A (USAF). Electromagnetic Interference - Test Requirements and Test Methods. Wright-Patterson Air Force Base, Ohio (30 June 1966).

(7) MIL-STD-461A. Electromagnetic Interference Characteristics - Requirements for Equipment. Wright-Patterson Air Force Base, Ohio (1 August 1968).

(8) McKAY, DEAN H. Current Status Electromagnetic Pollution Management and Measurements. Fairchild/Electro-Metrics Corporation, Burbank, Calif. (August 1970).

(9) SHEPPARD, A. P. and R. G. SHACKELFORD. Spectrum Surveillance Procedures for Obtaining a Profile of Electromagnetic Pollution for a Given Area. Georgia Institute of Technology (memo dated May 19, 1970).

(10) BARSIS, A. P. M. E. JOHNSON, and M. J. MILES. Analysis of Propagation Over Irregular Terrain in the 76-to-9200 MHz Range ESSA Technical Report ERL 114-ITS 82, U.S. Department of Commerce, Boulder, Colo. (March 1969).

# APPENDIX A

## LIST OF TRANSMITTERS IN THE LAS VEGAS, NEVADA, AREA

| Transmitter | Code | Frequency | Effective Radiated Power | Transmitter Location | |
|---|---|---|---|---|---|
| | | | | Latitude | Longitude |
| KORK TV VIDEO | 0 | 61.25 | 100 kW | 36 07 50 | 115 05 06 |
| KORK TV AUDIO | 1 | 65.75 | 17.4 kW | 36 07 50 | 115 05 06 |
| KHBV TV VIDEO | 2 | 77.25 | 64.6 kW | 36 00 26 | 115 00 23 |
| KHBV TV AUDIO | 3 | 81.75 | 12.9 kW | 36 00 26 | 115 00 23 |
| KLAS TV VIDEO | 4 | 181.25 | 200 kW | 36 07 49 | 115 09 52 |
| KLAS TV AUDIO | 5 | 185.75 | 5.5 kW | 36 07 49 | 115 09 52 |
| KLVX TV VIDEO | 6 | 193.25 | 296 kW | 35 57 53 | 115 30 00 |
| KLVX TV AUDIO | 7 | 197.75 | 35 kW | 35 57 53 | 115 30 00 |
| KSHO TV VIDEO | 8 | 211.25 | 204 kW | 36 07 44 | 115 11 21 |
| KSHO TV AUDIO | 9 | 215.75 | 40.7 kW | 36 07 44 | 115 11 21 |
| KVEG FM | A | 92.3 | 44 kW | 36 07 15 | 115 10 27 |
| KORK FM | B | 97.1 | 44 kW | 36 07 50 | 115 05 06 |
| KLUC FM | C | 98.5 | 10 kW | 36 07 46 | 115 10 17 |
| KRGN FM | D | 101.9 | 20 kW | 36 08 40 | 115 09 07 |
| FAA VARIOUS | None | 75-175 | 40-200 W | McCarran Airport, Pahrump Nelson and Boulder City | |
| Misc. * | None | 150 | Less than 1 kW | Various Fixed and Mobile Locations in Las Vegas | |

* Includes industrial, public safety, and transportation services operating around 150 MHz.

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# APPENDIX B

## DESCRIPTION OF SAMPLING SITES

### East-West Grid Lines

T-1 Tropicana Ave. at Buffalo Drive
S.E. corner, no power lines

T-2 Tropicana Ave. at Rainbow Blvd.
50' west of intersection, no power lines

T-3 Tropicana Ave. at Jones Blvd.
300' west of intersection, power lines 50' north

T-4 Tropicana Ave. at Decatur Blvd.
300' west of intersection, 50' below average terrain

T-5 Tropicana Ave. at Valley View Blvd.
N.E. corner, power line 50' north

T-6 Tropicana Ave. at Las Vegas Blvd. South
300' east of intersection (Hotel Tropicana)
power lines 75' north

T-7 Tropicana Ave. at Bermuda Road
S.E. corner

T-8 Tropicana Ave. at Maryland Parkway
150' west of intersection (near telephone booth)

T-9 Tropicana Ave. at Eastern Ave.
200' west of intersection

T-10 Tropicana Ave. at Pecos Rd.
50' east of intersection, high voltage power lines
cross at intersection

T-11 Tropicana Ave. at Lamb Blvd.
100' north of intersection

T-12 Tropicana Ave. at Nellis Blvd.
0.1 mile east of intersection

T-13 Tropicana Ave. at Power Line Road
0.1 mile east of intersection

C-1 Charleston Blvd. at Rainbow Blvd.
50' south of intersection. Telephone line E-W on Rainbow Rd.

C-2 Charleston Blvd. at Jones Blvd.
100' west of intersection

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C-3 Charleston Blvd. at Decatur Blvd.
50' northeast of intersection (Mobil Service Station)

C-4 Charleston Blvd. at Valley View Blvd.
75' north of intersection (Water District parking lot)

C-5 Charleston Blvd. at Rancho Road
25' southeast of intersection (Standard Service Station)
Street light wires 20' west of antenna, no power lines within 75'

C-6 Charleston Blvd. at Main Street
250' west of intersection (Texaco Service Station)

C-7 Charleston Blvd. at Maryland Pkwy.
50' east of intersection (Standard Service Station)
Service station sign 20' N.W. of antenna

C-8 Charleston Blvd. at Eastern
150' east of intersection (Dairy Queen)

C-9 Charleston at Mojave Road
50' east of intersection 20' south of E-W. power lines

C-10 Charleston Blvd. at Lamb Blvd.
100' west of intersection
Street light power 20' north of antenna

C-11 Charleston Blvd. at Nellis Blvd.
100' east of intersection, E-W power lines near antenna

C-12 Charleston Blvd. at Sloan Lane
50' north of intersection, primary power lines 100' north
Elevation about 100 feet above average terrain

L-1 Lake Mead Blvd. at Jones Blvd. (dirt road)
100' east of intersection and N.S. power lines

L-2 Lake Mead Blvd. at Decatur Blvd.
100' west of intersection and N.S. power lines

L-3 Lake Mead Blvd. at Tonopah Hwy.
75' east of intersection and power lines

L-4 Lake Mead Blvd. at Tonopah Drive
N.E. corner

L-5 Lake Mead Blvd. at H Street
100' east of intersection, no power lines nearby

L-6 Lake Mead Blvd. at Fifth Street
S.W. Corner - 50' south of intersection

L-7 Lake Mead Blvd. at 25th Street
100' southeast of intersection

L-8 Lake Mead Blvd. at Pecos Street
50' east of intersection

L-9 Lake Mead Blvd. at Lamb Blvd.
N.W. corner - 50' west of intersection and power lines

L-10 Lake Mead Blvd. at Nellis Blvd.
N.W. corner - 50' west of intersection

L-11 Lake Mead Blvd. at Sloan Street
S.W. corner

L-12 Lake Mead Blvd. at Power Line Road
50' north of intersection, 30' west of N-S power line
elevation about 100' above terrain

North-South Grid Lines

25-1 See L-7

25-2 25th Street at Owens Avenue
75' south of intersection (Texaco Service Station alley)

25-3 25th Street at Bonanza Road
200' south of intersection

E-1 See C-8

E-2 Eastern Avenue at Sahara Avenue
70' south of intersection

E-3 Eastern Avenue at Desert Inn Road
150' east of intersection (Phillips Service Station)

E-4 Eastern Avenue at Flamingo Road
100' north of intersection

E-5 See T-9

E-6 Eastern Avenue at Russell Road
150' south of intersection

E-7 Eastern Avenue at Sunset Road
75' north of intersection

E-8 Eastern Avenue at Warm Springs Road
75' north of intersection

E-9 Eastern Avenue at Windmill Lane
25' west of intersection

D-1 Decatur Blvd. at Craig Road
N.E. corner, no power lines

D-2 Decatur Blvd. at Gowan Road
S.W. corner, no power lines

D-3 Decatur Blvd. at Cheyenne Ave.
50' north of intersection, no power lines

D-4 Decatur Blvd. at Smoke Ranch Road
50' west of intersection, E.W. power lines 30'

D-5 See L-2

D-6 Decatur Blvd. at Vegas Drive
250' west of intersection (Shell Service Station)

D-7 Decatur Blvd. at Nebraska
50' west of intersection

D-8 See C-3

D-9 Decatur Blvd. at Sahara Ave.
50' south of intersection

D-10 Decatur Blvd. at Desert Inn Road
50' west of intersection

D-11 Decatur Blvd. at Flamingo Road
400' south of Flamingo Road

J-1 Jones Blvd. at Flamingo Road
N.W. corner, E-W power lines on other side of road

J-2 See T-3

J-3 Jones Blvd. at Russell Road
S.W. corner (dirt road)

P-1 Pecos Road at Craig Road
50' south of intersection, N-S power lines 100' west

P-2 Pecos Road at Gowan Road
50' south of intersection

P-3 Pecos Road at Cheyenne Road
S.E. corner, N-S power lines 50' west

P-4 Pecos Road at Carey Avenue
50' south of intersection, high voltage power lines cross at intersection

P-5 See L-8

X-1 Southwestern Radiological Health Laboratory Compound
no power lines nearby

# APPENDIX C

## COMPUTER PROGRAM FOR DETERMINING DISTANCE, ANGLES, AND CALCULATED POWER LEVELS

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                PROGRAM MWSURV(INPUT,OUTPUT,TAPE2=INPUT,TAPE5=OUTPUT)
000003          DIMENSION POWER(14),CODE(14),FREQ(14),ERP(14),XSTATN(14),
                1YSTATN(14),Q(14),THETA(14),POWERN(14),POWERE(14),POWCAL(14),
                2APOWER(14),ARATIO(14),RATIO(14),DIST(14),F(14),POWERNA(14)
000003          DO 70 I=1,14
000005          READ(2,60) CODE(I),FREQ(I),ERP(I),XSTATN(I),YSTATN(I),Q(I),F(I)
000026       60 FORMAT(7X,A1,F6.1,E7.1,2F6.0,E10.3,33X,F4.2)
000026       70 CONTINUE
000030          WRITE(5,100)
000034      100 FORMAT(*1*,/////,63X, *APPENDIX E*,///, 57X,*BICONICAL ANTENNA DAT
                1A*, ////,6X, *KORKTV   KORKTV   KHBVTV   KHBVTV   KLASTV   KLASTV
                2  KLVXTV   KLVXTV   KSHOTV   KSHOTV   KVEGFM   KORKFM   KLUCFM   K
                3RGNFM*,/,6X, *VIDEO    AUDIO    VIDEO    AUDIO    VIDEO    AUDIO
                4  VIDEO    AUDIO    VIDEO    AUDIO*,//)
000034      200 READ(2,210) DATAPT,XDATA,YDATA
000046      210 FORMAT(A3,2F5.0)
000046      300 IF(EOF,2)600,400
000051      400 READ(2,410) DATAPT,(POWERNA(I),I=1,11)
000065      410 FORMAT(A3,12X,11(A4  ,1X))
000065          READ(2,420) (POWERNA(I),I=12,14)
000077      420 FORMAT(15X,3(A4  ,1X))
000077          READ(2,401) DATAPT,(POWERE(I),I=1,11)
000113          READ(2,402) (POWERE(I),I=12,14)
000125      401 FORMAT(A3,12X,11(F4.1,1X))
000125      402 FORMAT(15X,3(F4.1,1X))
000125          DO 430 I=1,14
000127          YDELTA= YDATA-YSTATN(I)
000131          XDELTA= XDATA-XSTATN(I)
000133          RSQUAR=YDELTA*YDELTA+XDELTA*XDELTA
000135          DIST(I)=SQRT(RSQUAR)
000141          POWCAL(I)=Q(I)/(RSQUAR*1.0E 04)*1000.
000145          IF(POWERNA(I) .NE. 4H    ) GO TO 421
000147          APOWER(I)=9H
000151          ARATIO(I)=9H
000152          GO TO 430
000153      421 DECODE(10,423,POWERNA(I))POWERN(I)
000163      423 FORMAT(F4.1)
000163      422 THETA(I)=ATAN(ABS(YDELTA/XDELTA))
000171          FACTORN=10.*ALOG10(COS(THETA(I))*COS(THETA(I)))
000203          FACTORE=10.*ALOG10(SIN(THETA(I))*SIN(THETA(I)))
000216          POWERN(I)=POWERN(I)-FACTORN
000221          POWERE(I)=POWERE(I)-FACTORE
000223          IF(THETA(I) .GE. 1.05) POWERN(I)=POWERE(I)
000230          IF(THETA(I) .LE. 0.524) POWERE(I)=POWERN(I)
000235          POWER(I)=(POWERN(I)+POWERE(I))*0.5
000241          XPNENT=POWER(I)/10.
000242          POWER(I)=10.**(XPNENT)*1000.*F(I)
000250          RATIO(I)=POWER(I)/POWCAL(I)
000253      424 ENCODE(10,425,APOWER(I))POWER(I)
000263      425 FORMAT(E9.2)
000263          ENCODE(10,426,ARATIO(I))RATIO(I)
000273      426 FORMAT(F9.5)
000273      430 CONTINUE
000275      500 WRITE(5,510) DATAPT, (APOWER(I),I=1,14),(POWCAL(I),I=1,14),
                1(ARATIO(I),I=1,14),(DIST(I),I=1,14)
000333      510 FORMAT(* *,A3,14A9  ,* UWOBV*,/,4X,14E9.2,* UWCAL*,/,4X,14A9,
                1* RATIO*,/,4X,14F9.1,* DIST *,/)
000333          GO TO 200
000334      600 WRITE(5,650)
000340      650 FORMAT(///, * UWOBV=OBSERVED POWER(MICROWATTS), UWCAL=CALCULATED P
                1OWER(MICROWATTS), RATIO=UWOBV/UWCAL, DIST=DISTANCE FROM RECEIVER T
                2O XMITTER(METERS)*, /,* NOTE:  THE OBSERVED AND CALCULATED POWER V
                3ALUES ARE PRINTED OUT IN E FORMAT NOTATION (BASE 10);  EXAMPLE:  2
                4.83E+02 = 283.*)
000340      999 STOP
000342          END
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